An evaluation of tablet-based apps for maths learning in young children with Down's Syndrome

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ABSTRACT

Raising mathematical attainment in primary school education is important nationally, particularly for students who have Special Educational Needs (SEN). Tablet technology is an accessible and practical platform to provide additional teaching and raise learning outcomes (Haßler, Major & Hennessy, 2015). A literature review, including a systematic search of the use of tablet-based apps in raising maths attainment for children with SEN, provides a critical review of the existing theory and evidence base.

The present study evaluates the impact of tablet-based maths applications (apps) for children in Key Stage One of mainstream school who have Down's Syndrome (DS). A case study methodology, with embedded single case experimental designs (SCEDs), was implemented to explore the effects of daily fifteen-minute use of the onebillion maths apps supported by a teaching assistant (TA), on maths attainment and engagement with maths learning. The learner's level of functioning and pre and post measures of maths attainment were triangulated. Qualitative data from interviews with the facilitators was used to explore their perceptions of the intervention's effects for children with DS, as well the factors affecting its implementation and accessibility.

Outcomes varied across participants, with three out of four cases engaging well the intervention and displaying a positive effect size in one of two repeated measures, analysed using visual analysis and effect size; maths attainment or engagement. Relationships within the data were observed that suggested the outcomes of the intervention were influenced by the child's pre-requisite skills and level of functioning. Facilitators' perceptions of the app were positive, sharing views that children had enjoyed their time spent learning on the app and reporting gains in a range of skills including maths knowledge, confidence and patience in the children. A discussion of factors affecting outcomes identifies a range of individual and environmental aspects; and features of the intervention.

Results are considered in relation to existing research and its theoretical explanations. A review of the design and analysis used, acknowledges design threats which influence the conclusions that can be drawn. Implications for the use of tablet-based maths

learning for children with SEN, future research and educational psychology are outlined.

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1 INTRODUCTION

The aim of this study was to explore the impact of tablet-based maths applications (apps) for children who have Down's Syndrome (DS). The intervention, developed by onebillion, is a series of maths apps designed for children between the ages of three to six years, closely related to the national curriculum. Existing research evidences the impact for typically developing children across various countries, from large group designs. The research aim here was to explore the apps effect at an individual level for children with Special Educational Needs (SEN[1]). The impact of the intervention on an individual's maths attainment and engagement with maths learning was explored. Information about implementation, accessibility and the adult support required to enhance engagement, was also captured.

1.1 BACKGROUND TO THE RESEARCH

The research was completed as part of the author's training on the Doctorate in Applied Educational Psychology at the University of Nottingham. As part of the course, the author spent two years on professional placement with a Local Authority Educational Psychology Service. The author had an interest in mathematical development and teaching of maths, from earlier experiences of supporting and teaching maths in a secondary school. Having had a personal strength in maths during her school years, the clear difficulty that some students had with maths caught her interest whilst supporting secondary school students.

Having studied the development of literacy and available evidence-based interventions in depth, the author was keen to complete research in the area of numeracy both for personal reasons and for professional development. Given the smaller amount of existing research on numeracy in comparison to literacy (Dowker, 2009), there was a need for more numeracy research.

The author became aware of the onebillion maths apps through the team of researchers at the University of Nottingham who had completed evaluations of its

[1] The author acknowledges the variance in the use of the two terms, SEN and SEND, in the literature. For the purpose of this research the term used by the literature being referred to will be used; elsewhere the author uses SEN.

impact on learners in Malawi (Pitchford, 2015) and the UK (Outhwaite, Faulder, Gulliford & Pitchford, 2018). Existing research had indicated positive outcomes for learners in Key Stage One, Early Years Foundation Stage (EYFS) One and Two, although in the UK its accessibility and impact for learners with SEN had not been explored. The researcher therefore wanted to explore the use of the intervention at an individual level with Key Stage One learners with Down's Syndrome, who frequently have difficulties with maths (Buckley, 2007).

1.2 Overview of Chapters

Chapter two provides an overview of the existing research surrounding the topic, which supports the understanding around and development of the research questions. This chapter includes a systematic literature review of the use of tablet-based maths learning for children with SEN.

Chapter three outlines the methodology and procedure used. The rationale behind the decisions are provided, along with the actions taken to reduce risk, and increase the reliability and validity of the data collected. The ethical considerations central to this piece of research are presented.

Chapter four contains the quantitative and qualitative data collected in the research process. The findings from each individual case study are presented, including the single case experimental design (SCED) analysis. The qualitative data is then collated across the cases, using a thematic analysis to address the appropriate research questions.

Chapter five then explores these findings in relation to the existing research. Acknowledgement is given to the limitations which may have influenced the data and impacted the conclusions. Implications of the findings for future research and educational psychology practice are then presented. Personal reflections from the research process are included.

Finally, Chapter six presents the final conclusions derived from the research, highlighting the data's unique contribution to the existing evidence base.

2 LITERATURE REVIEW

The following review presents an outline and analysis of the current literature on the topic of using tablet-based mathematical apps for children with SEN.

Firstly, the context and educational policy surrounding teaching maths in the UK is presented, followed by the theoretical understanding of the development of basic maths skills. The political drive for the inclusion of individuals with SEN to be educated in mainstream schools (Education Act, 1981), has meant that the role of the Educational Psychologist (EP) has been to help increase schools capacity to provide for those with SEN and create inclusive educational environments (British Psychological Society, 2002). With the increasing availability and use of technology in the classroom, the last decade has seen a rise in research into the impact tablet-based learning can have on educational outcomes (Haßler, Major & Hennessy, 2015), and its beneficial use for those with SEN.

A systematic review of the use of tablet-based learning in maths for children with SEN is included. A clear account of the search strategy, and the inclusion criteria, are outlined, before a detailed summary of the included studies. Following the analysis of the included research, key themes are identified and discussed.

The literature into a specific population of SEN; Down's Syndrome (DS) is then examined. Children with DS have difficulties with numeracy (Buckley, 2007) and may benefit from the learning opportunities available through tablet-based learning.

Finally, the themes and reviewed literature are drawn together to describe the rationale for the current study and the research questions to be investigated.

2.1 EDUCATIONAL CONTEXT: MATHS AND NUMERACY

In comparison to literacy, the research into numeracy is limited, although an increase has been recognised since the introduction of the Primary National Strategy (Dowker, 2009). The importance of basic maths skills is clear through to adulthood, where at the age of 30, the evidence suggests that poor numeracy rather than poor literacy is related to low economic well-being (Parsons & Bynner, 2005). Estimations suggest that

between 15-20% of the population have difficulties with basic arithmetic (Dowker, 2009).

Children completing Key Stage 2 (aged 7-11 years old) with a level four or above in maths rose between 1998 and 2007 (Williams, 2008); however, concerns are held about the lowest achievers. Dowker (2009) suggests, despite the improvements in overall levels, the gap between the highest and lowest is growing and the "problem of severe underachievement has remained consistent and significant" (p.4). Detailed understanding of the processes involved in the learning of mathematics is important given the significant impact of poor mathematical skills (Cragg & Gilmore, 2013). Early intervention is needed to prevent the difficulties influencing other areas of the curriculum, as well as preventing any negative attitude or anxiety towards maths from developing (Dowker, 2009).

Before examining the research into maths teaching and appropriate interventions, factors which are considered to have a long-term impact on mathematical development are presented.

2.1.1 Pre-requisites of Mathematical Development

The cognitive predictors of maths development are well researched, although here two well-documented pre-requisite skills linked to mathematical attainment will be briefly outlined. These are language ability (Donlan, Cowan, Newton & Lloyd, 2006) and executive function (Cragg & Gilmore, 2013). Further details in this area are examined later in relation to a specific SEN population (DS, Section 2.4.2).

Language is fundamental to education as the main method of instruction and representation of knowledge (Cowan, Donlan, Newton & Lloyd, 2005). The research indicates the influence that young children's language skills can have on their mathematical development and future academic attainment (Hornburg, Schmitt & Purpura, 2018; Purpura, Hume, Sims & Lonigan, 2011; Vukovic & Lesaux, 2013). Literature shows that young children's general language skills predicts mathematical attainment in childhood (Purpura et al., 2011; Toll & Van Luit, 2014). Language is considered to be fundamental in understanding mathematical content and it is understood to predict gains in mathematical skills in data analysis, probability and

geometry (Vukovic & Lesaux, 2013). However, language ability may not be related to arithmetic and algebra skills (Vukovic & Lesaux, 2013) where manipulation of known numerical quantities is essential.

More recently, the evidence indicates that mathematical language is more specifically related to numeracy skills than general language ability (Hornburg et al., 2018). Mathematical language is a child's understanding of key words in mathematics; for example, 'more' and 'less' referred to as quantitative words, and spatial words such as 'before' and 'after'. Hornburg et al. (2018) found that for participants aged between three and six years old, mathematical language was specifically related to numerical skills including those early basic skills of verbal counting, one-to-one correspondence and numeral identification, more than general language ability. These results suggest the importance of mathematical language in assessment and intervention of early numeracy skills.

Working memory, the ability to maintain a representation of information whilst engaging in other mental processes, is related to an individual's performance in several number tasks. Both the early ability to count (Healy & Nairne, 1985) and an individual's strategy of choice used to complete basic and complex addition problems (Geary, Hoard, Bryd-Craven & DeSoto, 2004) are influenced by working memory. Working memory, along with the cognitive processes of inhibition and shifting, are often referred to under the umbrella term of Executive Function (EF).

EF skills are needed to behave flexibly and adaptively in new situations (Van der Van, Kroesbergen, Boom & Leseman, 2012), key to the learning process. Research indicates that good EF skills provide children with an immediate head start in mathematics in the learning environment (Bull, Andrews, Espy & Wiebe, 2008). Although the definition of EF is inconsistent in the research, Cragg & Gilmore (2014) provide a recent, theoretically grounded definition, applicable to educational settings. The authors propose a theoretical model which predict relationships between the different components of mathematical knowledge and EF skills (Figure 2-1).

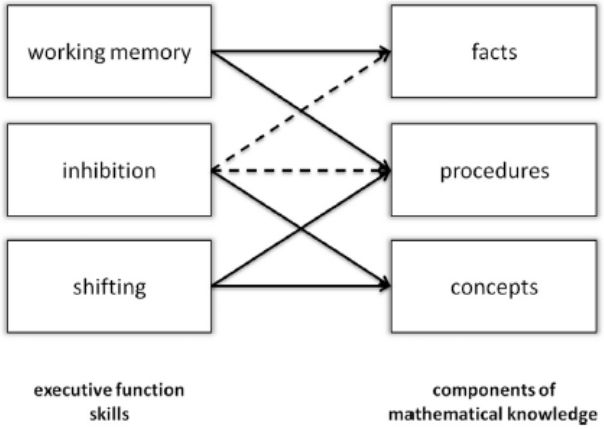


Figure 2-1: A model predicting relationships between executive function skills and mathematical knowledge types by Cragg and Gilmore (2014).

The three key components of EF (working memory, inhibition and shifting) are likely to have different influences on factual, procedural and conceptual mathematical knowledge at different developmental stages. In the early stages of establishing core factual mathematical knowledge, working memory is likely to play an important part in holding new information in the mind, but possibly also inhibition to suppress responses to similar questions (Cragg & Gilmore, 2014). An outline of the different types of mathematical knowledge is provided next.

2.1.2 Concepts in Mathematics

The development of mathematics is based on the acquisition of several different components; factual, conceptual, mathematical reasoning and problem solving (Outhwaite et al., 2018). Factual knowledge consists of basic facts such as number bonds, shape and size. Conceptual knowledge is then identifying and using mathematical procedures. Both factual and conceptual knowledge are understood to

make up basic maths skills, required before the higher level of processing for reasoning and problem solving can develop. At these higher levels of processing, pupils can make inferences from mathematical information (reasoning) and then apply it in different contexts (problem solving).

Research has shown that the development of higher order mathematical skills is dependent on the acquisition of basic maths facts, including counting (Geary, 2011). Gelman & Gallistel (1978) analysed the skills needed to develop the basic skill of counting, outlining five underlying principles. They suggest these are:

- *One-to-one correspondence* – the principle that only one word tag is assigned to each object
- *Stable order* – the understanding that the order of these word tags is invariant
- *Cardinality* – the final value of the word tag represents the quantity in the group
- *Abstraction* – objects of any kind can be collected and counted
- *Order-irrelevance* – items within a set can be tagged in any sequence.

Given the importance of these basic skills in mathematical development, research has examined the most effective methods of teaching pupils to achieve a level of mastery.

2.1.3 Effective Maths Instruction

Educators have examined what may support the acquisition of basic maths skills, particularly for SEN students or struggling learners.

Direct (or explicit) instruction is a well-established method which research indicates as an effective method of instruction for the teaching of maths (Gersten & Carnine, 1984). This involves a highly structured teaching technique, where students are given all the information needed to complete the task and errorless learning is encouraged (Gulliford & Miller, 2015). Despite the appealing approach to 'learning through minimal guidance' and 'learning through discovery' it is argued that there is not a sufficient body of research to support it (Kirschner, Sweller & Clarke, 2006). Explicit instruction, providing clear modelling and guided practice to independence is thought to benefit students with maths difficulties (Fuchs et al., 2008).

A second principle is practice, the need for a high level of repetition (Fuchs et al., 2008). Effects of practice on mathematical arithmetic has been demonstrated, impacting both strategy selection and strategy efficiency (Imbo & Vandlerendonck, 2008). Opportunities for overlearning supports maintenance and generalisation of skills (Haring & Eaton, 1978). According to the instructional hierarchy, repetition and reinforcement of a skill promotes future use of the skill in different contexts (Haring & Eaton, 1978).

Another feature of effective maths instruction is the use of visual representations (Gersten et al., 2009). The use of physical and concrete models, allowing children to actively manipulate representations, aids understanding (Gersten et al., 2009; Hirsh-Pasek et al., 2015). Immediate feedback for the learner on their progress and effort develops motivation, encouraging students to regulate their attention and behaviour (Gersten et al., 2009).

Although schools are encouraged to use evidence-based interventions (Education Endowment Fund, 2017), personalisation of the curriculum is also important. Fuchs et al. (2008) recognised that although these interventions may work for most students; they may not work for all. Effects should be monitored on an individual basis. Principles of instructional psychology allow the pupil's attainment to become the assessment to inform future tasks (Gulliford & Miller, 2015). Technology provides an opportunity to create this individualised learning environment.

2.2 RAISING ACHIEVEMENT USING TECHNOLOGY

The use of technology, both computers and hand-held devices, in the classroom has been a matter of debate. Shin et al. (2012) argue that technology has positive effects on motivation, persistence, curiosity, attention and attitude to learning, and that mobile tablet devices, for example, can be used to take advantage of gaps in classroom teaching to maximise learning. Notwithstanding, there are arguments against the use of technology for children suggesting that there may be negative consequences on physical, social, emotional, and intellectual development (Cordes & Miller, 2000; Dinehart, 2015). Advocates for the use of technology would argue that these studies

often do not discriminate between interactive and non-interactive activities on technology (Miller, 2018).

Formal evaluation of the use of technology in the classroom to support early mathematical skills is needed to build the evidence base for its efficacy. A review of the data suggests that results must be interpreted with caution as the quality of the research can be questioned. Cheung and Slavin (2013) highlight that due to poor methodologies used in the research, effect sizes are often inflated. “Common problems include a lack of control group, limited evidence of initial equivalence between treatment and control group, large pre-test differences, or questionable outcome measures” (Cheung & Slavin, 2013, p.4).

An overall positive effect is suggested, of technology-based educational games on developing maths skills in the early years, children aged between four and seven (Outhwaite, Gulliford & Pitchford, 2017). Although the effect sizes do vary from small (Cohen’s d>0.4, Räsänen, Salminen, Wilson, Aunio & Dehaene, 2009) to large (Cohen’s d>0.8, Pitchford, 2015). Two studies from Europe (Räsänen et al., 2009; Praet & Desoete, 2013) and one from America (Shin et al., 2012) have reported significant effects of maths games on a technological device in comparison to normal practice or alternative game.

Questions have arisen from this research around the extent to which the effects of technology-based educational games are maintained post the intervention and the extent to which the skills are generalised beyond the material in the intervention. Räsänen et al. (2009) found, with children aged six years old, that their intervention group remained significantly different from the control group at a delayed assessment however, this was only 3 weeks post intervention. The results also indicate that only four out of twenty calculated effect sizes were significant, and the significant differences were only found in a number comparison task which was one of four tasks used to measure number skills (Räsänen et al., 2009).

With the increasing investment of technology in education, alongside a policy-driven push for the inclusion of those with SEN in mainstream education, it is necessary that

educators and researchers critically consider the use of technology to support pupils with SEN (Florian, 2004).

2.2.1 Tablet Technology and SEN

Technology may provide conditions for "equal opportunity to learn and equal access to the curriculum" (Florian, 2004, p.10) for those with SEN. Purpose can take a variety of forms including as a form of communication, assessment or using the skills of the tools it can provide. In relation to raising numeracy attainment, the focus here is on the use of technology as a tutor. As discussed earlier, existing research has reported positive effects of technology for maths learning (Cheung & Slavin, 2013); however, a different teaching approach is often needed for those with SEN (Van Luit & Schopman, 2000).

Tablets, in comparison to desktops and laptops, are light and portable, increasing the ability to incorporate their use into the mainstream classroom (Zhang, Trussell, Gallegos & Asam, 2015). The long battery life also supports the use of them across an extended period in different settings. Pitchford, Kamchedzera, Hubber & Chigeda (2018) also suggest that another advantage, particularly for those with SEND, is that the additional dexterity of using a keyboard and mouse is not needed. On the other hand, many of the educational software programmes designed for use on tablets require a significant level of sensory processing and manual coordination, which could limit their accessibility for those with SEND (Pitchford et al., 2018).

The instructional methods of software on tablet technology, including explicit instructions and immediate feedback, provide potential benefits for using them in the teaching of those with SEN. Children with SEN often require higher levels of instructions to maintain, retain, and transfer their learning (Day & Hall, 1988). Tablet software allows the creation of an individualised learning environment, key for students with SEN to work at their own pace and receive immediate feedback. The creation of an individualised learning environment is supported by "multiple representations of information, such as pictures, video, and animation, varying or progressive levels of task difficulty, clear goals and rules, learner control, task feedback, and repetition" (Pitchford et al., 2018, p.3).

Haßler, et al. (2015) completed a systematic review of the evidence of tablet use on learning outcomes. Of the twenty-three studies that were included in the final review, positive results were reported by sixteen of the studies with only two reporting a negative impact. Notably only one study was related to Maths (Riconscente, 2013), which used a repeated measures experimental design to evaluate the impact of a Maths fraction app - 'Motion Math'. A positive impact was seen; however, the intervention was only for a week. This was also a universal study and did not consider the impact on SEN pupils. Three of the studies identified in Haßler et al.'s (2015) review examined the impact for SEN studies, nevertheless, all were literacy based.

Research into the impact that tablet software has on the maths attainment of students with SEN is needed (Zhang et al., 2015). Zhang et al. (2015) in an exploratory study found that three maths apps had the bigger impact on 'struggling' students in comparison to 'typical' students. Acknowledged by the authors, there was a small sample size and short duration of the intervention meaning findings cannot be generalised. Recently some studies have added to this literature (e.g. Outhwaite et al., 2018). A critical review of the evidence of such apps with this population is therefore called for (Section 2.3). Beforehand, an outline of the intervention used in this research, which has more recently been considered for use with a SEN population is presented.

2.2.2 Onebillion tablet-based Intervention

2.2.2.1 Features of the intervention

Onebillion is an educational not-for-profit company (www.onebillion.org.uk) which has developed a series of apps with the aim of improving children's basic literacy and numeracy in the early years of school. The maths apps (Maths age 3-5 and Maths age 4-6) are a series of carefully structured apps designed in line with the national curriculum requirements. Given their similarity and progressive content they are treated as one intervention for research. The apps cover a range of topics included in the National Curriculum for Key Stage One (Department for Education, 2014). They primarily aim to develop factual and conceptual knowledge of number, shape, space and measure (Outhwaite et al., 2018), initially focusing on developing an understanding of numbers to 20, counting skills and basic calculation (Walton, 2018).

Principles of instructional psychology (Gulliford & Miller, 2015), can be seen to underpin the design of the app's curriculum presentation, using a 'virtual' teacher to provide clear modelling and instruction to guide children through the apps. They are designed to be colourful and engaging activities, providing progressive content with immediate feedback for the learner. Children must achieve 100% to pass the quiz at the end of each topic. To create a personalised learning environment, each child has a profile on the software to save their progress, allow them to learn at their own pace and allow completed topics to be revisited if further practice is required.

2.2.2.2 Evaluation Research

The apps have been subject to evaluation in the UK and Malawi by researchers at the University of Nottingham (see Appendix 8.1 for a summary of the existing research). Pitchford (2015) reported the first randomised controlled trial of the maths apps in Malawi. As children in Malawi are educated in groups of ability rather than age, children from standards 1-3 (*n*=282) were randomly allocated to one of the three groups; maths app group, a placebo group using a tablet for non-maths activities, or normal teaching. Three measures of mathematical ability were designed to be used for the assessment, two of which were tablet based and a third paper and pencil task. Following eight weeks of intervention, 30 minutes per day, all the pupils in the maths app intervention group improved more than the normal teaching and placebo group. However, effect sizes illustrated that the intervention had a varying impact on curriculum knowledge and mathematical concepts at the different standard levels.

Outhwaite et al. (2017) and Outhwaite et al. (2018) have since evaluated the use of such tablet-based learner-centred software in the UK, a country of much higher-income and more structured education system. The results provide further evidence for the use of such technology to support children in the EYFS and Key Stage One early maths skills, with effect sizes reported being similar to or greater than that of Pitchford (2015).

The demographics of the control groups in the first reported study (Outhwaite et al., 2017) limited the conclusions that could be made. In the first study, the performance of the EYFS students were compared to that of Key Stage 1 students who had normal maths teaching. This meant that the maths abilities were understandably different,

and measurements from the Year 1 students were only taken pre-test so normal progression of their ability was not measured. In the fourth study, the intervention group consisted of low achievers and they were compared to a control group of age-matched individuals who were relatively high-achieving. Cheung and Slavin (2013) identified large pre-test differences as a common methodological issue with the research.

These limitations were overcome by the first pupil-level randomised control trial (Outhwaite et al., 2018) in which participants were randomly allocated to one of three groups and statistical analysis found no significant differences between groups at pre-test. The results led to conclusions that the onebillion apps provide "effective means of delivering quality instruction that promotes the development of early math skills" (Outhwaite et al., 2018, p.10). Discussion has also emerged about the potential mechanisms underpinning the efficacy of the intervention, accounting for individual differences and implementation factors on outcomes (Walton, 2018).

Outhwaite et al. (2017) found evidence that the app was "particularly beneficial for low-achieving pupils" (p.52) however, this was not consistent with data from Walton (2018) whose data indicated the low-attaining nursery children showed less progress with the app. Exploration of its use with the SEN population is scarce. An observational study (*n*=33) in Malawi investigated whether children with SEND could be supported in their mathematical development by the interactive app intervention (Pitchford et al., 2018). With a broad classification of SEND in Malawi encompassing children with a diverse range of needs including sensory, physical, cognitive, and social and emotional difficulties, the authors used teacher ratings of the level of disability as an indication of need. Data suggested that pupils with SEND can learn basic mathematical skills through the intervention, although their rate of progress was slower than that of mainstream pupils. The rate of progress was also influenced by the level of disability rated by the teachers. A UK study with a more detailed understanding of the nature of difficulties of the pupils with SEN is required before the intervention can be recommended as an appropriate teaching method for pupils with additional learning needs.

2.2.3 Summary of using technology to raise achievement

In summary, the use of tablet-based technology for maths learning has an increasing evidence base for typically developing children (Shin et al., 2012). With the movement towards inclusive education for those with SEN in mainstream classrooms, researchers have recognised the benefits that tablet-based learning may provide. Although, many have not systematically evaluated the outcomes of such type of learning for those with SEN. Some initial exploratory studies have suggested positive results (Outhwaite et al., 2018; Zhang et al., 2015). A systematic review will be used to aggregate the current evidence base for tablet-based maths apps with children with SEN, allowing key features of context, methods and data to be reviewed (Gulliford, 2015).

2.3 Systematic Literature Review

The systematic literature review will consider the existing research into the use of mathematical apps with students who have SEN.

Systematic reviews are often considered as the highest level of research, helping to remove the bias and preference for significant findings often seen in other types of research (Gulliford, 2015). "They are a method of critically appraising, summarising and attempting to reconcile the evidence in order to inform policy and practice" (Petticrew & Roberts, 2008, p. 15). The potential of technology to support those with SEN can take different forms (Florian, 2004) but reviews of the literature have highlighted the need for more research on the impact of educational apps with this population (Stephenson & Limbrick, 2015).

Gough's (2007) Weight of Evidence (WoE) framework for analysing data in a systematic review was used to evaluate the effect of mathematical apps on students with SEN, having proven useful in professional educational psychology. The search procedure and inclusion criteria used will be outlined before a description of the selected studies. These selected studies are then appraised for quality and relevance to formulate a conclusion of the existing research evidence.

2.3.1 Review Question

What is the effectiveness of mathematical apps presented on tablet devices on the learning attainments of children (aged 18 or under) with SEN?

2.3.2 Systematic Search

A systematic search was conducted to identify the available research on children with SEN and their use of mathematical apps on tablet devices. From the research question the key words 'mathematical apps', 'tablet' and 'special educational needs' were identified. To ensure a thorough search, these terms were broadened using synonyms. The full set of terms used for the search can be seen in

'tablet' OR 'iPad' OR 'touchscreen'	AND
'maths app' OR 'numeracy app' OR 'mathematical app'	AND
'special educational needs' OR 'learning difficulties' OR 'SEN' OR 'developmental disorders'	AND

Table 2-1: Key words and synonyms used for online database searches

During July 2018, Nottingham University's online database search (NUSearch-UK) which allows access to a diverse collection of databases, was used to conduct the search. Key word searches were also completed on ERIC and Google Scholar, capturing any articles that were not available through the first database search used. Reference lists of articles identified were scanned to look for articles which had not been seen which might be relevant to the question.

2.3.3 Inclusion Criteria

To ensure the articles reviewed were up-to-date and relevant the following inclusion criteria was applied:

1. The research examined the impact an app on a tablet device had on the mathematical attainment of students (aged 18 or under).
2. The apps impact on students with SEN had been explored. If students without SEN had also been used in the study, the effects of the intervention on those with SEN could be examined individually.
3. The research had been completed since 2009 when the first tablet devices were made available.
4. The research was published in a peer reviewed journal.
5. The research was in the English Language.

2.3.4 **Search Results**

Once the potentially relevant studies had been obtained, articles were screened by their titles and abstracts to assess for eligibility (*n*=249). Fifteen suitable articles were subsequently read as full texts to finalise the inclusion of each article; eight were identified as meeting the inclusion criteria outlined above. Appendix 8.2 is a visual flow-chart showing how the results were narrowed down to the final eight studies. See Appendix 8.3 for the details of the excluded research and reasons why.

Table 2-2 presents a systematic map of the eight pieces of research which met the inclusion criteria. This table includes details of the sample, design, measurements and outcomes of each study.

Author and Year of publication	Sample	Design	Intervention Details	Measures	Outcomes
Bryant, Ok, Kang, Kim, Lang, Bryant & Pfannestiel (2015)	6 students Learning Disabilities Aged 9 years old	Single Case alternating treatments design Three conditions: App-based (AI) Combined (CI) Teacher-directed (TDI)	30 mins daily intervention for 3 weeks App based instruction for multiplication (Maths Drill/Maths Evolve)	2 min multiplication probe daily Social Validity Questionnaire	No condition emerged as consistently better All approaches were favoured by at least one student
Calder & Campbell (2016)	41 Students Aged 16-18yrs. Reluctant leaners who left school without qualifications	Case Study of 3 classes Interpretative Research Methodology	Range of Maths Apps chosen by teachers and external consultants Across 6 months	Semi-structured group interviews pre and post Attitudinal surveys Class observational data Online assessment of numeracy skills	Changes in attitudes towards numeracy. Enhanced engagement and provided challenges to learning in a non-threatening way. Overall greater than expected improvement between initial and final on-line numeracy assessments.
Chmiliar (2017)	8 Preschool children Aged 3-5yrs old With Disabilities	Mixed-method approach Action Research with 8 case studies embedded within.	Duration of 21 weeks Range of apps dependent on focus of cycle iPad available at home and school	Pre and post semi-structured interviews with parents and teachers. Observations in the classroom	All children made learning improvements Some had difficult accessing iPad initially Attention and engagement reported to be enhanced.

				Informal criterion-based classroom assessment before and after each cycle	Verbal improvements seen in many of the cases All parents spoke positively about the iPad as a learning tool Teachers raised some limitations.
Fernandez-Lopez, Rodrigues-fortiz, Rodriguez-Almendros & Martinez-Segura (2013)	39 students SEN including Autism, Down's Syndrome, Fragile X, ADHD or Pervasive Developmental Disorder Mean age 11.8yrs Ranged from 4 to 20 yrs.	Non-experimental design Pre and Post assessments	Researcher designed Interactive and Cooperative Platform to Support Learning - Picaa 4 months access to Picaa	Questionnaire on basic skills by teacher Evaluation questionnaire by student	Maths skills were increased 5.56% on average Statistically significant differences in all skills considered.
Kaur, Koval & Chaney (2017)	10 students Special needs Students in fourth grade (9-10yrs old)	Non-experimental Qualitative analysis	2 hours each week for 5 weeks 10 free math apps in addition to traditional teaching methods	Weekly reflections from teachers followed by an open-ended survey at the end	Confirmed use of iPad to support conceptual mathematical understanding. 6 themes identified: Using iPad as a guide, informal assessment tool, different learning styles, mathematical understanding, engagement, independence,

					participation and individualised instruction.
Ok & Bryant (2016)	4 students Aged 10-11yrs Learning Difficulties	Single Case multiple probe design	Math Evolve 15 1:1 intervention sessions over 3 weeks 2 weeks maintenance assessment	Multiplication probe Social Validity questionnaire	All students made significant growth in multiplication fact performance. The effect size results indicate a significant large effect for all participants. Participants had positive perspectives about the intervention
Pitchford, Kamchedzera, Hubber & Chigeda (2018)	33 Primary School Children Mean age – 9.85 Teacher ratings of extent of disability	Observational design using correlational analysis	Onebillion Maths Apps 1-hour daily session	Teacher ratings of Pupil Disability Educator Ratings of Pupil Interaction with technology Rate of Progress (time spent on tasks passed)	SEND pupils can interact with technology. Lower disability slightly greater interaction (although not significant) All completed at least one topic SEND mean progress rate – 242 mins Mainstream progress rate – 127 mins Significant relationship between progress rate and disability score (p=0.033) Significant negative relationship between attention and their progress rate (p=0.045)
Zhang, Trussell, Gallegos & Asam (2015)	18 participants Mean age – 9 4 students with SEN including autism,	Non-experimental exploratory design Pre and Post assessments	Three Maths Apps – Splash Math, Motion Math Zoom and Long Multiplication	Three paper and pencil assessments were administered.	Differences between pre and post tests were all statistically significant. Struggling group made larger gains in three assessments – achievement gap between two groups was reduced.

	emotional disorder, dyslexia and learning disability.		4 maths classes over one month – 80-90-minute sessions		

Table 2-2: Systematic mapping of the details of eight pieces of research which met inclusion criteria

2.3.5 Research quality and relevance appraisal

Gough's (2007) WoE framework was used to complete the quality and relevance appraisal of the eight studies which had met the inclusion criteria. This framework provides a structured format to make generic and review-specific judgements about what a study contributes to answering the review question (Gough, 2007). Using ratings of high, medium and low each study was weighted for its contribution. The three judgements (WoE A, B and C) are made before making an overall judgement (WoE D). Each piece of research was weighted as high, medium or low depending on how many of the criteria were evident from the study. The criteria (see below) and judgements made (Table 2-3) were made by the author and therefore acknowledgment is given to the possibility of bias. A coding method to quantify the quality of each study, allocating a score for each criteria, may have provided a more explicit and reliable approach. Quantifying how many of the criteria are provided could have been used to label them has high, medium or low dependent on their score (for example see, Walton, 2018).

Before outlining the judgment made for each study, an outline of the criteria that was used to make the judgments is presented.

WoE A is a generic and non-review specific judgement about the research in terms of its coherence and integrity. For many research methods, researchers have created criteria for evaluating the quality of the evidence, used to guide the WoE A judgement (Gough, 2007). The research included a variety of different designs and therefore the most relevant guiding criteria was used for each; qualitative research, single case experimental designs (SCED) or group experimental research.

For those studies using a SCED, design standards outlined by Horner et al. (2005) and Kratochwill et al. (2013) were used. The key elements include:

- Clear and operationalised dependent variables
- Multiple measurements in each phase, with a stable pattern established in the baseline
- Active manipulation of the independent variable

- Replication across participants, behaviours or contexts to improve external validity.

Gersten et al. (2005) outlined quality indicators for group experimental designs. The quality indicators proposed are:

- Sample characteristics described and comparable across groups
- Attrition rates reported
- Implementation fidelity measured and reported
- Reliability for outcome measures provided
- Data analysis clear with descriptive, inferential statistics and effect sizes.

Finally, the included studies involved qualitative research. Credibility measures of such designs are outlined by Brantlinger, Jimenez, Klingner, Pugach & Richardson (2005) as:

- A clear and explicit audit trail of the data collected and its synthesis
- External auditors/collaborative work to ensure others would make the same inferences and that interpretations are not biased
- Information is triangulated from different sources
- Participants had the opportunity to review and confirm the accuracy of the data collected.

WoE B is a review-specific judgement about the appropriateness of that form of evidence for answering the effectiveness review question (Gough, 2007). The level of experimental control, presence of a control or baseline condition, and the validity and reliability of the measures used influenced the judgement made. The appropriateness of the design was rated high, medium or low.

WoE C is also a review-specific judgement but refers to the relevance of the focus of that study for answering the question of this review (Gough, 2007). The research's sample and focus on the mathematical nature of the app and outcomes was used to make the judgement. The participant's age and SENs were contributors. Ratings of high were given if the app was specifically a maths app and the outcomes of mathematical knowledge were evident.

An overall rating, based on the judgements of WoE A, B and C, was then allocated for each piece of evidence (WoE D). Providing an overall assessment of the extent to

which that piece of research contributes to answering the review question (Gough, 2007).

Table 2-3 presents the weightings given to each of the eight studies included in the review. Appendix 8.4 contains the key points raised from the authors critical analysis of the individual papers and used to inform the judgements made.

	WoE A Coherence and integrity of the research design.	**WoE B** Design with good experimental control. Good reliability and validity	**WoE C** A School age sample with clear descriptors of SEN. Clear mathematical outcomes reported.	**WoE D** Overall weighting
Bryant et al. (2015)	Low	Medium	High	Medium
Calder & Campbell (2016)	Low	Low	Low	Low
Chmiliar (2017)	Low	Low	Medium	Low
Fernandez-Lopez et al. (2013)	Low	Low	Low	Low
Kaur et al. (2017)	Medium	Low	Low	Low
Ok & Bryant (2016)	High	High	Medium	High
Pitchford et al. (2018)	High	Medium	High	High
Zhang et al. (2015)	Low	Low	Medium	Low

Table 2-3: Weight of Evidence ratings for eight included studies

2.3.6 Research Synthesis

A narrative synthesis of the final eight studies included is presented next. Following the production of the systematic map (Table 2-2) and detailed analysis of the research, emerging themes and factors are outlined. These included sample characteristics, design, intervention implementation, impact on maths achievement, and impact on student's attitude, motivation and engagement. Although studies given a 'low' rating are included, they do not change the conclusions of other studies (Gough, 2007) as those with higher rating were more influential.

2.3.6.1 Research Design

Due to a limited number of studies which were available and met the inclusion criteria, a range of research designs were included.

SCEDs were used by two of the included studies (Bryant et al., 2015; Ok & Bryant, 2016). SCED methodology provides a systematic evaluation of an intervention at an individual level, a well-documented design within the subject of special education (Horner et al., 2005). Bryant et al. (2015) used an alternating treatment design, a technique recognised to increase experimental control (Kratochwill et al., 2013). Their design involved five sessions of three different treatments over a three-week period and found no evidence of a condition being consistently better (Bryant et al., 2015). This result could be explained by the lack of consistency experienced by the participants, not allowing any treatment to have a significant effect. A more rigorous design, a single-case multiple probe design across participants, demonstrated a more consistent effect of app-based learning with a staggered introduction of the intervention (Ok & Bryant, 2016). Both studies (Bryant et al., 2015; Ok & Bryant, 2016) provide some experimental control, beyond that which can be offered by case studies.

The remaining studies used designs which do not have the experimental control to make causal inferences despite all reporting positive results. The studies which used non-experimental case study designs (Calder & Campbell, 2016; Chmiliar, 2017) report positive results. Chmiliar (2017) strengthened their results by using eight individual cases (Yin, 2009). Case studies are limited by constraints including low internal validity and lack of generalisation. Other designs included non-experimental designs with no

control group (Zhang et al., 2015; Fernandez-Lopez et al., 2013), observational designs (Pitchford et al., 2018) and qualitative designs (Kaur, Koval & Chaney, 2017).

2.3.6.2 Sample Characteristics

Another factor evident from the literature is the sample of participants used, particularly age and SEN status. Due to heterogeneity of the SEN population, small sample sizes were expected; the smallest sample being four participants (Ok & Bryant, 2016) and the largest being forty-one (Calder & Campbell, 2016). School aged participants were used in all but two studies, which used pre-schoolers (Chmiliar, 2017) or students post-16 (Calder &Campbell, 2016). All other studies reported had an age range or mean age between nine to eleven years old. Key Stage One children (aged 5-7) were not used by any of the included pieces of evidence.

The inclusion criteria required the research to involve participants with SEN. Synonyms of 'learning difficulties', 'SEN' and 'development disorders' were included given the range of terminology used by practitioners. The research included participants with a 'diagnosis' of a learning difficultly, disability or SEN, however, the sample used by Calder & Campbell (2016) were termed as 'reluctant learners'. They described their sample as having "had no formal literacy and numeracy qualifications and a large proportion had left school without any qualifications" (Calder & Campbell, 2016, p.57). This study is less relevant to the question and therefore its weighting represents this (Gough's 2007 framework presented in section 2.3.5). Pitchford et al. (2018) was conducted in Malawi, an underdeveloped country without an established classification system for SEN, and therefore the researchers used teachers' ratings as a measure of disability. A heterogenous sample of children with SEN are likely to have diverse and distinct needs.

2.3.6.3 Intervention Implementation

The intervention implementation varied between the studies, a feature which Cheung & Slavin (2013) identified as impacting the results reported. The studies covered a range of apps including onebillion maths app (Pitchford et al., 2017), Maths Evolve (Bryant et al., 2015; Ok and Bryant, 2016), Maths Drill (Bryant et al., 2015), Splash Math, Motion Math Zoom and Long Multiplication (Zhang et al., 2015). Fernandez-Lopez et al. (2013) used a researcher developed software programme called 'Picaa'

that was not maths specific hence the studies low rating in the WoE framework in section 2.3.5. Instead it was a mobile platform with four kinds of educational activities including Exploration, Association, Puzzle and Sorting. The control over the amount of access that was available varied, with one study allowing participants access to the apps at home and school (Chmiliar, 2017).

Cheung and Slavin (2013) highlight that short periods of intervention are more likely to report positive results than those that monitor the effects of long-term intervention and maintenance; a minimum period of 12 weeks is recommended. The two pieces of evidence which used a controlled and systematic experimental approach (SCED) to their design only measured impact over three weeks (Bryant et al., 2015; Ok & Bryant, 2016). Ok & Bryant (2016) also reported positive effects at a maintenance assessment, however, this was only two weeks post the three-week intervention phase.

2.3.6.4 Impact on Maths Attainment

The inclusion criteria ensured that all the included studies reported the impact of the intervention on the mathematical attainment of the participants. Kaur et al. (2017) used a qualitative method to data collection to do this, interviewing the teachers who were involved in implementation. A theme which was identified through the qualitative data analysis was “Using iPads to Develop Mathematical Understanding” (Kaur et al., 2017, p.188). The teachers shared that the iPads allowed mathematical skills to be presented visually, broken down into small steps and could receive instant feedback; all supporting mathematical understanding for students aged nine to ten years old.

All but one study (Bryant et al., 2015) reported positive effects on maths attainment. However, due to the nature of the designs, making causal inferences is difficult. The two studies which were rated high for coherence and integrity against quality criteria (Ok & Bryant, 2016; Pitchford et al., 2017) are amongst those reporting positive results suggesting that overall the use of maths apps appears to benefit students with SEN in relation to maths attainment. In both instances, participants were within the age range of seven to eleven; equivalent to Key Stage Two in the UK. Ok and Bryant’s (2016) use of a multiple probe design across participants demonstrates the intervention’s impact; with effect sizes indicating a significant effect across all participants. However, the app

was used amongst a more structured teacher led intervention therefore the impact the app use had alone is not able to be seen.

Pitchford et al. (2017) used monitoring data available from the software company who provided the intervention to monitor the progress in learning maths for their participants who had SEND in Malawi (mean age = 9.85) Their data suggests that children with SEND completed at least one topic (a series of activities followed by a quiz to assess a particular skill) on the app, however the time taken to complete a topic (234mins) was longer than mainstream pupils (127mins). This progress rate also had a significant positive relationship to the individual's disability level. With further analysis the authors found that "pupils with more severe difficulties with hearing and/or language took longer to progress through the apps than pupils with relatively good hearing and language skills" (Pitchford et al., 2017, p.9).

2.3.6.5 Impact on Attitude, Motivation and Engagement

A final theme identified from the analysis of the included studies was the impact that app-based learning has on student's attitude, motivation and engagement. Both studies which used a qualitative approach (Calder & Campbell, 2016; Kaur et al.,2017) report that participants were more engaged in their learning, willing to learn (Kaur et al.,2017) and had an improved attitude towards mathematics (Calder & Campbell, 2016). Neither of these two studies had any direct measure or quantitative evidence of these outcomes though.

A social validity questionnaire was used by Bryant et al. (2015) and Ok & Bryant (2016) to measure the participant's perspective on the interventions after the intervention phase of the SCED was complete. Bryant et al. (2015) had participants, aged nine, rate app-based learning in comparison to teacher directed or a combined approach. Two out of six of the participants reported they preferred app-based learning. Notably, there were no votes for app-based learning being the approach which helped them learn the most. Ok & Bryant (2016) used a similar approach of a social validity interview asking participants questions on their perspectives about intervention components and the overall intervention. Although participants, aged between ten and eleven, were positive about the use of apps, three out of four participants preferred working with the investigator using flashcards or worksheets.

The attention the students paid towards their learning when involved with mathematical apps was also discussed in the research. None of the included research provides any evidence other than qualitative comments that there was increased attention. Chmiliar (2017) completed observations of the pre-schoolers engaging with the apps and stated that three out of eight were observed to be able to sustain attention in the activities for longer periods of time. No indication of how this was evidenced or recorded is provided however, and therefore this should be interpreted with caution.

These results suggest that although students may enjoy engaging with mathematical apps, this is not sufficient alone. Apps for maths learning need to be well scaffolded and supported by adult interaction. More quantitative data is needed before conclusions can be made about the impact apps have on children's attitude, motivation and engagement.

2.3.7 Summary and conclusion of systematic review

In summary, the systematic review for literature regarding the impact of mathematical apps for children with SEN, generated eight studies which met the inclusion criteria. Using Gough's (2007) WoE framework it was evident that much of the research was given low weighting due to poor methodological design or lack of relevance to the question being asked. Few of the studies could infer causality, highlighting a need for more rigorous research in the area.

Sample characteristics and intervention implementation were two other factors limiting the credibility of the research. The nature of SEN was diverse, and studies ranged in their definition and clarity in the children's learning needs. Small samples and heterogeneity of the population result in limited generalisation.

The positive impact that maths apps can have on maths attainment of children with SEN is indicated by these exploratory studies' findings. However, due to limitations discussed earlier, conclusions are made with caution. The research also indicates the need for app use to be integrated into a well-structured teaching programme and supervised by an adult. More rigorous controlled experimental designs are needed to allow causal inferences to be made in the future.

The final section of this literature review will examine the literature surrounding the use of tablet-based maths learning for children with a diagnosis of DS. This population was of interest for this research due to evidence that suggests that children with DS often have greater difficulty with numeracy than literacy (Buckley, 2007).

2.4 DOWN'S SYNDROME

DS also referred to as Trisomy 21, is a genetic condition affecting between 1 in 1,000 to 1 in 1,100 people worldwide (World Health Organisation). Individuals with DS have an extra 21st chromosome due to an error in cell division, that results in both cognitive and physical disability (Faragher & Clarke, 2013). With an increasing life expectancy and a movement towards inclusive education the importance of understanding the cognitive abilities of those with DS has become important to practitioners.

Agheana and Duţă (2015) report that DS is the "most common cause of intellectual disability" (p.38). The cognitive abilities of those with DS vary, however executive function, memory and language are commonly impaired (Startin et al., 2016). Misconceptions have been held in the past about the educability of this population (Turner & Alborz, 2003), with some authors recognising a historical view that only a very small proportion of those with DS ever learn to read or write (Macpherson, 1999). Others would argue that this was due to a lack of information on the educational potential of those with DS (Rynders et al., 1997).

Evidence from a longitudinal study of increasing abilities in measures of AAI (Academic Attainment Index), Reading, Writing and Number across time has demonstrated that academic progress is possible (Turner & Alborz, 2003) for those with DS. With the introduction of policies such as the Education Act (1981) and the Special Educational Needs and Disability Act (2001) the education of those with SEN within mainstream education has been the focus in the UK. A report by Turner, Alborz and Gayle (2008) on the predictors of academic attainment of those with DS, found that mainstream education was associated with higher attainments.

2.4.1 Mathematical Development and DS

Children with DS often appear to have difficulties with numeracy (Buckley, 2007; Sella, Lanfranchi & Zorzi, 2013), with evidence suggesting that the achievements of those

with DS in numeracy are lower than their literacy achievements (Bird & Buckley, 2001). Quality of life and independence for those with DS is reported to be enhanced by a basic understanding of numeracy (Buckley, 2007).

Research into the basic numerical skills of children with DS is "relatively sparse, despite the fact that these abilities might be at the heart of their math underachievement" (Sella et al., 2013, p.3799). Research is inconsistent as to whether the nature of the difficulties frequently seen are a result of a delay or a specific difficulty.

Paterson, Girelli, Butterworth & Karmiloff-Smith (2006) compared the development of number skills and understanding of participants with two different genetic disorders; Williams Syndrome and DS, across a range of age groups including young infants and adults. They found that children with DS (mean age -30months) could not discriminate between two and three objects, however young adults (mean age-24years old) performed in line with controls on a number discrimination task. The results suggest that the developmental stages and acquisition of early number skills follow a similar trajectory to that of typically developing peers despite being a great deal slower. Camos (2009) found that the performance of children aged between five and eight with DS, when discriminating between larger sets of objects, was comparable to typically developing peers. A recent review concluded that children with DS have difficulty with comparing small numbers of objects, but this difficulty is not seen with larger set sizes (Porter, 2019).

Sella et al. (2013), found evidence of a specific deficit in the Object Tracking System (OTS), a preverbal system which allows young infants to accurately perceive the number of small sets (between three or four objects) often referred to as subitising. Results from their match- to-sample tasks indicated that children (mean age – 14:2years) with DS had an impairment with subitising in comparison to controls matched for both chronological age (CA) and mental age (MA). Whereas the Approximate Number System (ANS) responsible for number estimation beyond the subitising range was similar to MA controls but not CA controls suggesting a delay rather than a specific deficit. Overall, the research evidence indicates that the mathematical underachievement of children with DS is likely to be a result of "weakness in these basic numerical skills that are thought to be foundational to

mathematical learning" (Sella et al., 2013, p. 3805). The cognitive profile of individuals with DS has provided further insight into mathematical underachievement.

2.4.2 Cognitive and Behavioural Phenotype

Individuals with DS have a distinct behavioural phenotype in language and cognition (Chapman & Hesketh, 2001) which is not characteristic of individuals with intellectual disability in general (Visu-Petra, Benga, Tincas & Miclea, 2007). Although a vast amount of research into the behavioural phenotype of individuals with DS exists and will be discussed in relation to mathematical development next, it is important to highlight the heterogenous nature of the population and wide variability in individual performance (Patterson, Rapsey & Glue, 2013). Therefore, although analysis of individual data is sometimes more appropriate, researchers have argued that the understanding of a behavioural phenotype can allow academic interventions to be tailored appropriately (Lemons, Powell, King & Davidson, 2015).

Characteristics of the behavioural phenotype of those with DS, which are predictors of maths development in the broader population, can therefore provide insight into the difficulties children with DS tend to have learning basic maths skills (Lemons et al., 2015). These characteristics of memory, language, attention and fine motor skills will be discussed individually next.

2.4.2.1 Memory

A fractioned profile of strengths and weaknesses in the cognitive domain of memory is reported for those with DS (Visu-Petra et al., 2007). Research evidence indicates that children with DS have relative strengths in visual-spatial memory (Visu-Petra et al., 2007) but have poor verbal/auditory short-term memory (STM) (Vicari & Carlesimo, 2006). The explanations of poor verbal STM in children with DS has been linked to the different components of working memory (Baddley & Hitch, 1974). As outlined earlier in Section 2.1, Bull et al. (2008), found that working memory and other executive function skills are predictors of early maths acquisition. However, the relative strengths in visual-spatial memory could provide a platform and method of intervention for maths teaching (Lemons et al., 2015).

2.4.2.2 Language

Another domain of typical difficulty for those with DS is language (Chapman & Hesketh, 2000). Children with DS have been found to have specific difficulties with expressive language more than receptive language. Chapman, Seung, Schwartz & Bird (1998) compared conversational and narrative language samples of individuals with DS (aged between 5-20 years) with controls who were matched for their non-verbal mental age. Results found that children with DS appear to have specific language impairments evident in the number of different words used, total words and mean length of utterances. Language is understood to be fundamental to education and delayed language development can limit access to all areas of the curriculum, including mathematics (Cowan et al., 2005).

One aspect of language development which has been linked to both DS and maths development is phonological processing (Lemons et al., 2015). A review of the research evidence found that children and adults with DS often underperform on phonological awareness tasks when compared to typically developing peers that were matched on either reading ability, mental-age or chronological age (Lemons & Fuchs, 2010). Research evidence has suggested that there is a relationship between preschooler's phonological awareness and acquisition of basic mathematical skills (Krajewski & Schneider, 2009). Krajewski & Schneider (2009) suggest that phonological processing impairs the "acquisition of verbal codes that are needed for numerical processing at an early developmental stage" (p.14). However, the researchers note that phonological awareness did not have a direct impact on higher numerical processing and can be compensated for in later maths development.

2.4.2.3 Attention

Attention is a skill which is often included as part of EF and is frequently an area of weakness for children with DS (Rowe, Lavender & Turk, 2006). Rowe et al. (2006) completed a between-groups design of DS adults, aged between 23-40yrs, compared with a control group who had learning difficulties but not DS. Amongst several EF skills which were measured, the researchers also attempted to measure attention. They used a visual search and cancellation test to measure Attention Sustained, requiring participants to strike out a target item within a time period, and found significant

differences between the two groups (p<0.01, d=1.22). Fidler (2006) proposed that the low levels of task persistence and distractibility seen in those with DS is also influenced by their strengths of social-emotional functioning. They suggest that children with DS who have poor task persistence as a result of difficulties with strategic thinking often naturally turn to their strengths in social skills and display social engaging behaviours when faced with a challenge. Attention has often been found to be a predictor of mathematical development (Bull et al., 2008; Fuchs et al., 2005).

2.4.2.4 Fine motor skills

A final area that provides a potential link between DS and poor mathematical understanding is fine motor skills (Lemons et al., 2015). Spanò et al. (1999) found evidence of difficulties with fine and gross motor skills in a sample of 22 school-aged children with DS. They used two assessments (Movement Assessment Battery for Children and Developmental Test of Visual-Motor Integration) to measure a range of gross and fine motor skills. Results indicated that in both tests those with DS scored below the 5th percentile. In comparison to gross motor skills, fine motor skills were more significantly impaired and showed little development with age. Pitchford, Papini, Outhwaite & Gulliford (2016) found that "fine motor skills were a better predictor of early maths ability than they were of early reading ability" (p. 1) and highlighted the importance of motor skill interventions in early education.

In summary, characteristics frequently seen in children with DS are known to be related to numerical ability in typically developing children. These characteristics, therefore, may help us to understand the difficulties often experienced by children with DS with maths and subsequently the most appropriate ways of supporting mathematical development.

2.4.3 Supporting mathematical development of those with DS

Due to the cognitive difficulties frequently experienced by children with a diagnosis of DS, difficulties are often had with processing, retrieving and assimilating visual and auditory information. Therefore, it is essential that adaptions and supporting strategies are used for learners with DS to be able to access learning in a mainstream classroom. Research outlines the most effect methods of instruction and scaffolding for teaching

maths (Section 2.1.3), although published research which focuses on teaching children with DS remains limited (Black & Wood, 2003). A summary of the available research into teaching early mathematical concepts to those with DS follows.

Germain (2002) provides some of the earliest advice on the way to support DS pupils with numeracy in mainstream education. This small-scale research design used structured observations to compare the experiences of whole class, group and individual teaching. Conclusions suggested that it is important to provide additional individual and small group support, particularly during the early years. However, participation in mainstream classrooms is still important, noting the improvements in behaviour of the case example in whole class settings.

Research into the possible interventions that are appropriate for use with the DS population is not in abundance. A systematic review of maths interventions for individuals with DS completed by Lemons et al. (2015) identified nine studies between the years of 1989 and 2012. The included studies used a range of designs including quasi-experimental designs and single-case designs. However, following the author's evaluation of quality, no studies were deemed to meet the standard of adequate quality. This therefore limited the conclusions that could be made, although some important points were made. A range of interventions were evaluated but "all interventions included aspects of direct instruction, modelling and guided practice" (Lemons et al., 2015, p.773). Only one of the included studies, discussed more in Section 5.3.1, used computer assisted teaching (Ortega-Tudela & Gómez-Ariza, 2006).

Even though limited by poor research designs, all the nine included studies reported positive effects on maths attainment, therefore indicating a need for an "increased quantity and quality of mathematics intervention research for children and adolescents with DS" (Lemons et al., 2015, p.780).

2.4.3.1 Use of Technology

Black & Wood (2003) have proposed that Information Communication Technology (ICT) can be used as a tool to differentiate and promote inclusion for those with DS, in addition to promoting development in specific areas. These areas include motor skills, speech and language, reading and writing, number skills, memory and social

development. “The use of ICT in the education of students with Down Syndrome offers a high motivation for learning, multi-sensory experience, non-verbal model of response, built environment, immediate feedback, sense of achievement, opportunities to practice, individual pace of learning, differentiation and adaptive technology” (Kyriakou, Charitaki & Kotsopoulou, 2015, p.160).

Ortega-Tudela & Gómez-Ariza (2006) highlighted that the DS population may benefit from the visual presentation of material, and the systematic, repetitive and individualised sequence which is possible with technology. An experimental pre-and post-group design was used with eighteen DS participants to compare the attainments of a group which were taught using multimedia to those who were taught the same content with a traditional paper and pen method (Ortega-Tudela & Gómez-Ariza, 2006). Statistical analysis was conducted on the data collected from measures of basic numerical ability, and results were found in favour of the multimedia. More recently, Agheana & Duţă (2015), have also found significantly greater improvements for a group of DS children given electronic apps compared to those given concrete objects for learning maths. Both studies had small samples, and the importance of further research is emphasised (Gersten, Baker & Lloyd, 2000).

2.5 Conclusion, Rationale and Research Questions

Following the theory and literature outlined in this review, the proposed piece of research aims to explore the effectiveness of the onebillion maths tablet-based intervention for children with DS in Key Stage One. Individuals with DS are known to have difficulties with Numeracy (Buckley, 2007; Paterson et al., 2006; Sella et al., 2013) and initial research has suggested the benefits of multimedia technology (Ortega-Tudela & Gómez-Ariza, 2006; Agheana & Duţă, 2015). The need for more objective and experimental evaluations for the population has been called for by other researchers, particularly research which consider the behavioural phenotype of the individuals (Lemons et al., 2015).

This research will also add to the existing evidence base of the onebillion maths intervention for which the research has indicated a positive impact for the universal population (e.g. Outhwaite et al., 2018). An initial exploratory study investigated its

use in Malawi with children with SEND (Pitchford et al., 2018). Experimental evaluation with the SEN population is required in the UK to consider the extent to which it is effective before it can be recommended as a supplementary resource to classroom learning, ideally mapping against the curriculum, for pupils with SEN. Research into practices which can support learners with additional needs to achieve in maths is needed (King, Lemons & Davidson, 2016).

Finally, with more children with SEN being educated in mainstream settings, staff in these settings and external professionals, such as EPs, require knowledge of and access to targeted interventions.

This study aimed to assess the impact of the maths apps on the achievements of those with DS in Key Stage One. The research questions are:

1) Can onebillion's maths applications raise the maths attainment of Key Stage One children with Down's Syndrome?

2) Can the use of tablet-based applications support the engagement of children who have Down's Syndrome in their learning?

3) What is the relationship between baseline executive functioning and language skills and an individual's rate of progress?

4) What were the facilitator's perceptions of the outcomes of tablet-based learning for the children with Down's Syndrome?

5) What factors influence tablet-based learning for children with Down's Syndrome?

3 METHODOLOGY

The following chapter provides a detailed outline of the methodology used. Before outlining the design of the current study, the research is positioned in the context of the paradigms of psychological and educational research. The rationale for the research design is presented, followed by an account of the selected design, highlighting ethical considerations and issues of reliability and validity.

3.1 PHILOSOPHICAL ASSUMPTIONS

EPs use research as a method of knowing or understanding the phenomenon of interest. The approach taken is influenced by the researcher's theoretical framework and paradigm of choice (Mertens, 2015). Historically, there have been two dominant but opposing paradigms of post-positivism and constructionism (Feilzer, 2010). An overview of these two approaches follows, in addition to an outline of the paradigm used by the researcher in the current study.

3.1.1 Alternative Research Paradigms

Post-Positivism

Post-positivists have developed the positivist understanding that there is one reality which can be discovered. They argue that this reality can only be understood imperfectly (critical realism, Guba & Lincoln, 1994). The epistemology (the nature of knowledge and how this is obtained) associated with this stance is that although the investigator's "theories, hypotheses, and background knowledge… can strongly influence what is observed" (Mertens, 2015, p.15), the investigator tries to remain neutral without the influence of personal biases by following methods rigorously. Quantitative experimental methods are dominantly used by post-positivists, as they allow the researcher to establish causal relationships between manipulated variables (Shadish, Cook & Campbell, 2002).

Randomised controlled trials (RCTs) are often described as the gold standard of experimental fixed designs but with problems that arise conducting experiments in natural settings such as random assignment, validity, ethical issues and control (Robson & McCartan, 2016), others have encouraged the use of designs such as the quasi-experimental designs (Shadish, Cook & Campbell, 2002) or SCEDs (Horner et al.,

2005). The SCED can be a useful method of creating evidence-based practice, which is encouraged in education (Horner et al., 2005). Authors, such as Reason and Morfidi (2001), propose the use of SCEDs as a balance between the scientific nature and ability to infer causality from large randomised trials and the in-depth description achieved from case studies.

Constructivism

The constructivist paradigm, in contrast to post-positivism, argues that knowledge is socially constructed. Knowledge is therefore local and specific to its context and those individuals experiencing it (Guba & Lincoln, 1994). Although constructions can be shared, multiple mental constructions can exist which may conflict (Mertens, 2015).

In comparison to the post-positivist paradigm, constructivist researchers do not believe there is an objective reality to be found. Instead a researcher from a constructivist paradigm aims to understand the constructions held by the participants, recognising the influence of the interaction between the participants and the researcher. Research is therefore used to develop a consensus construction that is more sophisticated than previous constructions (Guba & Lincoln, 1994). The methodologies used within the constructivist paradigm often take "a more personal, interactive mode of data collection" (Mertens, 2015, p.19) including interviews and observations. A hermeneutical approach taking multiple perspectives is often sought to strengthen the interpretations of meanings.

3.1.2 Researcher's paradigm

In social sciences, post-positivism and constructivism still dominate methodological textbooks and epistemological debates (Feilzer, 2010). However, the researcher here uses the paradigm of Pragmatism. Pragmatism "focuses on the problem to be researched and the consequences of the research" (Feilzer, 2010, p.7). In comparison to other paradigms, pragmatism does not believe that knowledge can be found using one single scientific method but rather a more real world and practical stance is taken.

Whereas other paradigms focus their designs on finding reality and the truth, a pragmatist is concerned with the social validity and usefulness of the findings through whatever design is most appropriate to answer the research questions. Methods are

judged by their ability to address the problem being investigated and purpose of the research. The researcher is in a position to "study what interests you and is of value to you, study it in the different ways that you deem appropriate, and utilize the results in ways that can bring about positive consequences within your value system" (Tashakkori & Teddlie, 1998, p.30).

Mixed methods research is often linked to the pragmatic paradigm, allowing the combination of quantitative and qualitative research to be used to explore multiple layers and perspectives (Feilzer, 2010). It is argued that a mixed methodology produces a more complete picture and is a way of building on, and developing, initial findings. There are several different designs used within mixed methods research, although a common feature is the analysis of both quantitative and qualitative data to form a multidimensional perspective (Feilzer, 2010).

This research used a single case design, with embedded SCEDs, to gather quantitative data evaluating the causal impact the intervention had on an individual's mathematical attainment and engagement in their learning. Additional data was collected through semi-structured interviews to gain insight into implementation and factors affecting outcomes. The supporting adults' perspectives allowed quantitative and qualitative data to be triangulated and more in-depth conclusions to be made.

3.2 STAKEHOLDERS

Stakeholders involved in the research included:

- Participating children and their parents
- The primary schools of which the participants attended, particularly the Special Educational Needs Coordinator (SENCo) and the adult(s) who supported the participants daily and facilitated the research.
- The Researcher
- The University of Nottingham

  Close liaison with other researchers from the University of Nottingham who had conducted previous evaluations of the onebillion intervention was important.
- The Educational Psychology Service

The researcher held a bursary training placement within the Educational Psychology Service (EPS) and therefore it was important that the research benefited the children and young people within this Local Authority (LA).

- The educational not-for-profit organisation, onebillion.
  The developers of the software, onebillion, were aware of the present research and its aims, providing the software free of charge to the participating schools.

3.3 SINGLE CASE DESIGN

The research used a mixed method design incorporating a single case design and semi-structured interviews to address the research questions (Section 2.5). Design details of the single case study method is next, outlining the choice of the method used to address each of the research questions. Section 3.4 outlines the additional qualitative data collected.

3.3.1 Single Case Design

A multiple case design was employed, with an embedded SCED within each case study.

Employing a case study methodology was deemed appropriate for this exploratory study as the method allows a phenomenon to be investigated whilst retaining the holistic and meaningful characteristics of real life (Yin, 2009). Although criticisms of the approach exist, Yin (2009) presents the argument that the case study methodology offers important evidence to complement experiments. Research into the intervention's efficacy and appropriateness for those with SEN is in its early stages, and likely to continue to beyond the scope of this study. The control over events also made the use of case study methodology appropriate, where contemporary events are investigated in contexts where some behaviours are not able to be manipulated.

To address the lack of rigour often associated with case study methodology, (Yin, 2009), an embedded SCED was employed. Such methodology allows greater causality to be inferred from the data (Kratochwill et al., 2013). Secondly, generalisability is raised as an issue for case study research. The purpose of case studies, however, is not to represent a sample and generalise to a population. Instead, the use of multiple case studies can be used to "expand and generalise theories… and not to enumerate frequencies" (Yin, 2009, p.15).

The use of single subject designs provides a method of evaluating the impact of an independent variable (e.g. an intervention) on one or more dependent variables for an individual. Commonly used within SEN research (Horner et al., 2005), participants act as their own control, allowing causal inferences to be made through reviewing the changes in performance observed between phases. Given the highly heterogeneous nature of children with DS, analysis of individual data rather than group, allows greater consideration of variation in individual performance (Patterson, Rapsey and Glue; 2013).

SCED features of repeated measurements across both baseline and intervention phases and systematic introduction of the intervention allows greater control and thus causal inferences at an individual level can often be made (Kratochwill et al., 2013). Researchers and practitioners within educational psychology have been attracted to the method because of its focus on the effectiveness of an intervention at an individual level (Mertens, 2015). There are number of different types of SCED designs, all with advantages and disadvantages. A feature which distinguishes between them is the level of internal validity. A discussion of the alternative SCEDs and the rationale for the chosen design follows.

3.3.1.1 Alternative designs and rationale for the chosen A-B Design

Notwithstanding the higher internal validity that alternative designs such as A-B-A or multiple baseline hold (Barlow, Nock & Hersen, 2009), a simple A-B design was chosen. The researcher acknowledges that it is the weakest form of SCED and thus conclusions are presented tentatively in Chapter 6. Ethical consideration was of priority and withdrawal of the intervention was judged ethically and professionally inappropriate. This meant that reversal designs, such as an A-B-A design, which involve removing the intervention for a phase, were not suitable. Due to the heterogeneity of the population and with each participant being in a different setting, it was also not possible to ensure other environmental factors would be controlled and therefore a multiple baseline design was not possible. The time and geographical constraints on the researcher also favoured the use of an A-B design.

An A-B design is a two-phase design including a baseline phase and intervention phase, in which repeated measures are administered on a regular basis. A baseline phase is

used to establish the individual's normal performance/rate of progress prior to the intervention. A stable baseline is recommended although researchers have recognised that this is not always possible (Robson & McCartan, 2016). The intervention is introduced after the establishment of a stable baseline and a minimum of 3 data collection points (Kratochwill et al., 2013) and the repeated measures continue. With participants acting as their own control, a change in the targeted behaviour between the two phases is looked for. The use of pre and post measurements with SCEDs provides supplementary data which can be triangulated with the repeated measures.

A visual map of the design is presented in Section 3.3.4, where the procedure is outlined.

3.3.2 Sample

3.3.2.1 Sampling Strategy

An opportunity sampling method was used by to identify participants who were available and met the needs of the research. All primary schools in the local authority were approached through the Expression of Interest Letter (Appendix 8.5) to identify schools who had a participant they thought met the inclusion criteria (outlined below in Section 3.3.2.2). All primary schools across the county were contacted through the link EP and the local authorities' school bulletin.

3.3.2.2 Inclusion Criteria

The inclusion criteria, to ensure eligibility for the research was:

1. The pupil held a diagnosis of Down's Syndrome.

2. The pupil was aged between 5-7 years old in Key Stage One in a mainstream primary school.

3. The pupil was not displaying behaviours which may make them unsuitable for accessing the intervention.

4. The pupil was not receiving any other targeted numeracy intervention.

5. The pupil did not have other significant difficulties which may hinder their access to the app, for example a significant visual impairment.

Table 3-1 provides a summary of the four participants which were included in the study.

Case	**Gender**	**Age** (years: months, at the start of research)	**School Year & Placement**	**Diagnoses**
Jimmy	Male	7:06	Year 2 (age-retained) Mainstream Primary	Down's Syndrome
Bobbie	Male	6:11	Year 2 Resource Provision in Mainstream Primary	Down's Syndrome
Millie	Female	7:07	Year 2 (age-retained) Mainstream Primary with Resource Provision	Down's Syndrome
Richie	Male	6:02	Year 1 Mainstream Primary	Down's Syndrome

Table 3-1: Basic participant information for the four cases involved

3.3.3 Quantitative Measures

A summary of measures, who completed them and at what time point in the study can be found in Table 3-2.

3.3.3.1 Measures used to address Research Question 1: Can onebillion's maths applications raise the maths attainment of Key Stage One children with Down's Syndrome?

Repeated Measure

To measure regular mathematical attainment a see-to-say one-minute probe was used, used regularly in educational research (Gulliford & Miller, 2015). Probes monitor the extent to which a pupil is accurate and fluent in a skill area being taught within their curriculum, using items pertinent to the individuals' curriculum, randomised (Gulliford & Miller, 2015). Here, probes presented simple visual maths tasks, requiring a verbal response. As a curriculum-based measure, the probe contains material relevant to each student e.g. digit recognition, early addition etc., and content therefore varied, consonant with the ipsative approach of the SCED method. These probes were therefore bespoke for each child, designed in collaborative consultation with the significant education staff around the child (e.g. SENCo and Teaching Assistant), to ensure the participant had a high likelihood of experiencing some success. Verbal responses were recorded by the teaching assistant[2] (TA). An example probe, developed by Raybould and Solity (2006), can be found in Appendix 8.6 and shows an example of a see-to-say probe where the student is required to state the number of dots present in each square.

Standardised Measure

The Sandwell Early Numeracy Test – Revised (SENT-R; Arnold et al., 2011) was employed pre and post intervention to measure each individual's maths learning and thereby aid triangulation of the repeated progress measures. The SENT-R (Arnold et al., 2011) was chosen as it is a standardised assessment which explores a pupil's ability with respect to five strands of basic numeracy skills: identification, oral counting, value, object counting and language. It can be used with children aged between 4-8 years old, testing a range of curriculum knowledge for those at a curriculum level between P6 and Level 2A. There are two versions of the test (Form A and B) to allow pre and post assessment without practice effects. The SENT-R (Arnold et al., 2011) has high internal reliability (Cronbach's alpha = 0.965) and a split halves reliability (Pearson's r = 0.962). The two parallel forms have high reliability (Pearson's r = 0.958).

The test takes between 10-30 minutes to administer individually. The test is highly visual, with the format of each question varying with the use of concrete materials and

[2] The author uses the terms Teaching Assistant (TA), Supporting Adult and Facilitator interchangeably depending on the context of which it appears.

colourful visuals. This reduces the demand of sustained attention on children. Dependent on the question, children are required to respond verbally, point to answers in the booklet or respond in a paper and pencil booklet.

The raw scores can be converted to standard scores, percentile ranks and age equivalent scores.

3.3.3.2 Measures used to address Research Question 2: Can the use of tablet-based applications support the engagement of those who have Down's Syndrome in their learning?

To measure engagement, an interval time sample structured observation (Appendix 8.7) was completed by the TA during the participant's engagement with a maths activity. During the baseline phase, this was taken during normal classroom maths learning and in the intervention phase whilst the child was engaged with the app. The TA recorded whether the participant was on or off task every 60 seconds for a duration of 10 minutes. This was converted to a percentage of time on task, to allow comparison of performances.

3.3.3.3 Measures used to address Research Question 3: What is the relationship between a child with Down's Syndrome's baseline language/executive function skills and rate of progress?

Standardised Measure

At pre-test only, subtests from the Developmental Neuropsychological assessment (NEPSY-II, Korkman, Kirk & Kemp, 2007) were used to assess language ability and executive functioning with each participant prior to the intervention starting, in the school setting. The NEPSY-II (Korkman et al., 2007) is a flexible set of subtests designed to allow the administrator to choose specific subtests, groups of tests or the whole battery (Brooks, Sherman & Strauss, 2009).

The 'Comprehension of Instructions' subtest from the language domain was used to measure the child's receptive language skills as the subtest can be used with children from 3 years old. The subtest requires children to respond to a verbal instruction by pointing to a stimulus such as "Show me a yellow bunny". Test-retest reliability for the subtest is good (Ages 5-6, Pearson's r = 0.80; Ages 7-8, Pearson's r = 0.79).

The 'Inhibition' subtest from the Attention and Executive Function domain was also administered. The subtest requires naming of squares as circles and circles as squares, combining verbal and visuospatial skills, and can be administered to individuals between 5-16 years (Henry & Bettenay, 2010). Different scores can be calculated from this subtest and for the age ranges of 5-8 years, the test-retest reliability varies from reasonable to good (Pearson's r = 0.66 – 0.82).

Questionnaires

Two paper and pencil questionnaires were completed by the child's TA to measure level of functioning. These were completed during the training session and handed back to the researcher immediately.

1. Washington Group Short Set of Questions on Disability

The Washington Group Short Set of Questions on Disability (Washington Group on Disability Statistics, 2019) is a set of six questions designed to identify functional skills across six core functional domains for people with disability. The questions are designed to identify if individuals have difficulty with walking, seeing, hearing, cognition, self-care and communication and was originally designed to be used with the general population. It has since been used in a variety of different contexts and settings, and research suggests it is a reliable and valid method of assessing the functional skills of individuals (Miller, Mont, Maitland, Altman & Madans, 2011). The wording of the questions was amended to ask an identified proxy person about the level of functioning of the child they work with. The questions can be found in Appendix 8.8.

2. SEND Rating Scale

The SEND rating scale, which can be found in Appendix 8.9, was designed and used by researchers investigating the use of the onebillion intervention with children with SEND in Malawi (Pitchford, et al., 2018). The use of this questionnaire was included to allow comparison with this earlier research. This questionnaire asks teachers to rate the extent of difficulty experienced by a child in key areas of functioning. For each area, teachers were asked to rate severity using a 4-point scale: 0 = no impairment, 1 =

mild impairment, 2 = moderate impairment, and 3 = severe impairment. Summing these ratings for each pupil generated a total disability score.

Research Question	Measures:	Measuring	When	By who
Can onebillion's maths applications raise the maths attainment of Key Stage One children with Down's Syndrome?	Sandwell Early Numeracy Test – Revised (SENT-R)	Mathematical Attainment	Pre-and post-intervention	Researcher
What is the relationship between a child with Down's Syndrome's baseline language skills and rate of progress?	NEPSY-II	Language	Pre-Intervention	Researcher
What is the relationship between a child with Down's Syndrome's baseline executive function skills and rate of progress?	NEPSY-II	Executive Functioning	Pre-Intervention	Researcher
What is the relationship between a child with Down's Syndrome's baseline language skills/executive function skills and rate of progress?	Paper and Pencil Questionnaire	Level of Functioning	Pre-Intervention	Teaching Assistant
Can onebillion's maths applications raise the maths attainment of Key Stage One children with Down's Syndrome?	Maths Probe	Mathematical Attainment	Repeated measures 2 x weekly for 9 weeks (Baseline and Intervention)	Teaching Assistant

Can the use of tablet-based applications support the engagement of those who have Down's Syndrome in their learning?	Time on task (Structured Observation)	Engagement	Repeated measures 2 x weekly for 9 weeks (Baseline and Intervention)	Teaching Assistant

Table 3-2: Table to show the quantitative measures used to address each research question including what it measured, when it was completed and whom by.

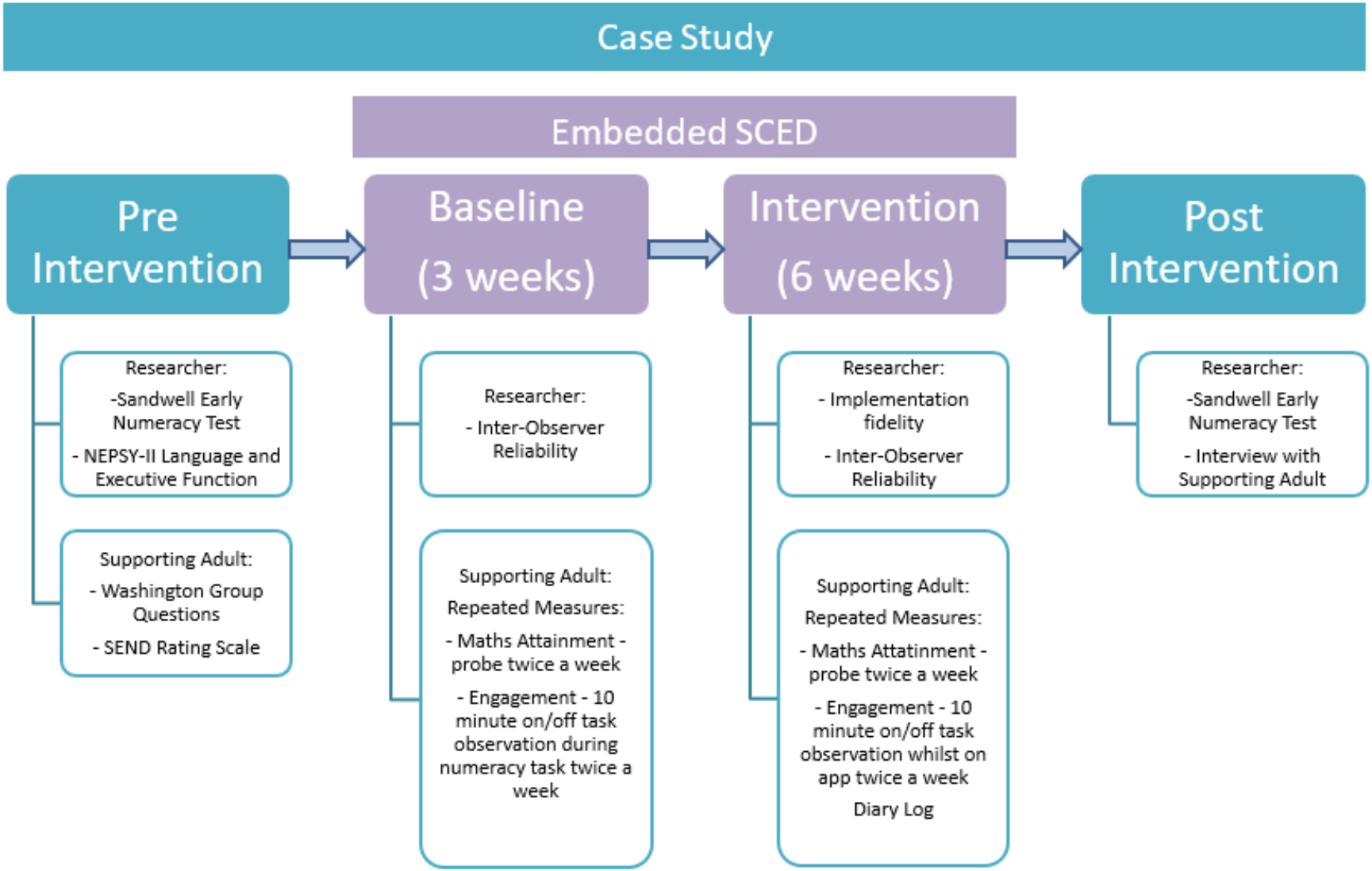


Figure 3-1: A visual representation of the methodology of the current study

3.3.4 Procedure

The details of the procedure follow, for which ethical approval was granted from the University of Nottingham (Appendix 8.18). Figure 3-1 provides a visual map of the methodology.

3.3.4.1 Pilot Phase

A pilot phase with one case was initially planned however, this was unable to be completed fully due to participant recruitment difficulties. Due to the limited number of participants meeting the inclusion criteria there were insufficient numbers to assign one child to a pilot phase. Robson & McCartan (2016) highlight the flexibility of the case study approach allows the researcher to learn during implementation and therefore a pilot can form a case in its own right. The first case began five weeks earlier than others to refine data collection plans. This case is presented like the other cases however as advised by Yin (2009), the "lessons learned for both research design and field procedures" (p.94) are made explicit.

3.3.4.2 Initial Contact

For each potential case identified through the Expression of Interest Letter (Appendix 8.5), an initial meeting was arranged through the school's SENCo, with the SENCo and the parents of the identified pupil. An open invitation to this meeting was given to the class teacher and TA. The SENCo was asked to share the Parental Information Letter (Appendix 8.12) with parents prior to this meeting if possible. This meeting was an opportunity to meet face-to-face with school and parents to explain the purpose of the research and what would be involved, and for them to ask any questions they may have. The guidance notes for this initial contact can be found in Appendix 8.10.

At the end of this meeting, information and consent sheets for school (Appendix 8.11) and parents (Appendix 8.12) were shared. The adults were given the choice of taking the information away and returning consent forms to school the following week, however in all cases, consent was gained at this initial contact.

3.3.4.3 Facilitator Training

A one-hour training session was held in the school setting between the researcher and the supporting adult of the identified child, who would be facilitating the research. Once the background, purpose and process of the research had been outlined, written

informed consent was sought from the supporting adult (Appendix 8.13). The supporting adult also agreed through this consent to take observational measures, and to being interviewed at the end of the intervention.

The TA was trained on the use of the two repeated measures they were asked to complete twice a week; a maths probe and structured observation. In consultation with the TA, an appropriate identified target skill to measure in the maths probe was chosen. Four versions of the randomised maths probe following this training session were designed and shared with school.

The supporting adult completed the two questionnaires (Appendix 8.8 & 8.9) about the individual's level of functioning at the end of the session.

A facilitator training sheet which summarised the training, and was shared with them, can be found in Appendix 8.14.

3.3.4.4 Pre-assessment

During the first week of baseline measurements (Section 3.3.4.5), the researcher completed a pre-intervention assessment with the individual child. This was done in a quiet room in the school setting. Before commencing, consent from the individual child was sought using the child-friendly information and consent form (Appendix 8.15). Details of the ethical considerations taken by the researcher can be found in Section 3.6.

The SENT-R (Arnold et al., 2011) Form A was administered first, following the resources administration manual. Additional measures of Language and Executive Functioning from the NEPSY-II (Korkman et al., 2007) were completed afterwards. These tests lasted no longer than 45 minutes if completed in full but were terminated at a point judged appropriate depending on the individual's concentration level. This professional judgment was made on the child's behaviour, level of distraction, engagement with the researcher and their verbal utterances. The researcher responded to requests from the child such as "No more" or "Can I go back to class?". In other incidences, non-verbal signals were used such as the child getting out of their seat regularly or finding something else in the room that distracted them.

3.3.4.5 Baseline

Consistent with SCEDs, prior to the intervention starting, repeated baseline measurements were taken. During this phase, normal teaching and school routines were maintained. The repeated measures of maths attainment (Section 3.3.3.1) and engagement (Section 3.3.3.2) were completed twice a week by the supporting adult.

The baseline phase lasted three weeks, allowing a maximum of six measurements to be collected. This was to ensure that the guidance of between 3-5 baselines measurements was met (Kratochwill et al., 2013). Although advised that baseline phases are extended until stability is achieved (Horner et al., 2005), time and ethical constraints restricted the baseline phase to three weeks.

3.3.4.6 Intervention

The intervention was the use of onebillion's maths apps, 'Maths Age 3-5' (Version 1.9, onebillion, 2018) and 'Maths Age 4-6' (Version 3.4, onebillion, 2018)[3] on tablet technology for 15 minutes a day for 6 weeks. A structured series of tasks, based on the key concepts of the National Curriculum (Number, Shape, Space and Measure) are presented on two apps used by the children individually on a tablet device. In this piece of research, due to the learning needs of many children with DS, it was expected that participants would work on the app in a quiet area with their TA on a 1:1 basis. Screen shots taken from the app are provided in Figure 3-2. Children worked through the apps at their own pace, providing opportunity for practice and repetition. Their progress through the tasks was saved in their profile, and once 100% has been achieved on a topic quiz, they received a certificate. "The apps are designed to be child-centred with content presented in attractive picture, audio and animation formats with interactive instructions, clear objectives and immediate formative feedback, consistent for all users" (Outhwaite et al., 2017, p.45).

[3] The onebillion maths apps (Maths Age 3-5 and Maths Age 4-6) are copyrighted and paid for applications. Full details regarding purchasing the applications and their content can be found on the onebillion (2018) website (https://onebillion.org/, accessed 24.09.18).

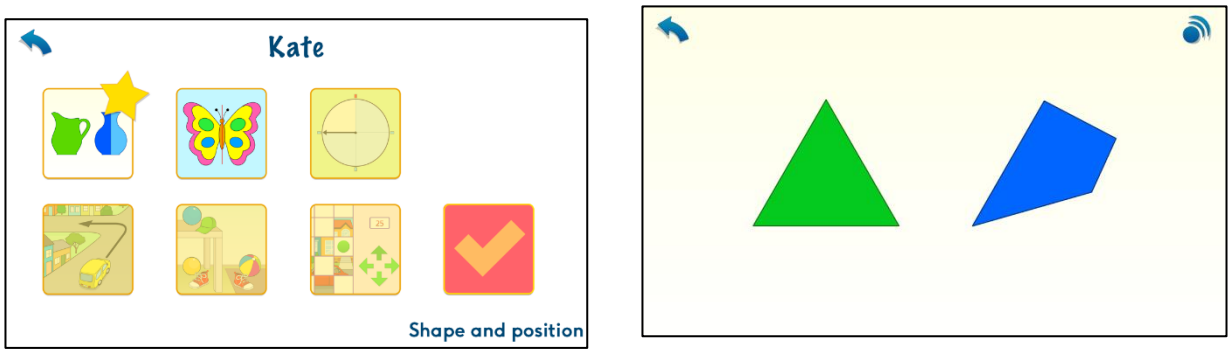


Figure 3-2: Example screenshots from the onebillion Maths apps

The recommended intervention length for research of twelve weeks (Cheung & Slavin, 2013) was not deemed suitable. Ethical issues arose from continuous assessment of a vulnerable group of young children for twelve weeks, and therefore the time frame was reduced to six weeks. A shorter time frame which allowed both baseline and intervention phases to be completed in nine weeks also ensured that data collection was only interrupted by one school holiday.

Fifteen minutes a day was less access time than previous research (Outhwaite et al., 2017; Outhwaite et al., 2018) where children accessed the app for 30 minutes a day for 12 or 13 weeks. Due to the age of the children participating and the attention difficulties experienced by children with DS, it was judged more appropriate to reduce the time to fifteen minutes. This time was also in line with research by Walton (2018) who investigated the apps effect for nursery aged children.

3.3.4.7 Post-assessment

At the end of the six-week intervention phase, a post-intervention assessment with each participant was completed. This involved a short individual assessment lasting no longer than 30 minutes between the child and researcher in a quiet room in the school setting. The SENT-R (Arnold et al., 2011) Form B was administered following the administration manual guidelines. See Section 3.3.3.1 for further details of the SENT-R (Arnold et al., 2011).

A semi-structured interview was also conducted with the supporting adult who had facilitated the intervention. Full details of this aspect of the research design is explained in Section 3.4.

3.3.4.8 Research Timelines

Implementation had intended to begin by October 2018 to have data collection complete by December 2018. However, due to difficulties with recruitment and commencement of data collection, delays were experienced, and data collection continued into January 2019. See Appendix 8.16 for the research timeline.

3.3.5 Single Case Data Analysis

3.3.5.1 Visual Analysis

Traditionally, visual analysis is used to determine the impact of the independent variable on the dependent variable (Kratochwill et al., 2013). Such researchers have argued that causal relationships are not demonstrated by inferential statistics but by careful methodological design and thus developed procedures of graphing and visually inspecting the data (Nock, Michel & Photos, 2007). Kratochwill et al. (2013) outlined standards of visual analysis of single case research, including consideration of four steps and six features of the data.

The first four steps recommended for visual analysis are:

1. A predictable and stable baseline is established
2. Visually examine the data within each phase to identify any patterns
3. Compare the data across different adjacent phases to assess whether the intervention can be linked to any change in the data
4. Use the data from all the phases to establish whether there are at least three demonstrations of an effect (notably in this research there was only two opportunities).

Kratochwill et al. (2013) then describe six features of the data that can be examined as part of the visual analysis process, see Table 3-3. Analysis of the data within each phase (Level, Trend and Variability) is used to describe the individual's performance and predict future performance if no changes were made. The three further features (Immediacy of the effect, Overlap and Consistency of data patterns across similar phases) examines patterns across different phases. With only one baseline and intervention phase for each behaviour, consistency of data was not possible in this study.

Feature	Definition
Level	Overall average (mean) within a phase.
Trend	The slope of the best fitting line for the measures taken in each phase.
Variability	The range and standard deviation are used to show the variability of the data around the mean during each phase.
Immediacy of the effect	The change in level between the last three data points of one phase and the first three data points of the next phase.
Overlap	Proportion of data from one phase that overlaps with data from the previous phase.
Consistency of data patterns across similar phases	Looking at all the data within the same phases to see if there is consistency.

Table 3-3: Features of visual analysis

Reliability of visual analysis has its limitations and must be recognised despite it being the most published analytical technique for single case research (Brossart, Parker, Olson & Mahadevan, 2006). It is criticised due to its subjective nature and common disagreements between raters (Brossart et al., 2006). Inter-rater judgments were completed to improve the reliability of the results (Section 4.8).

3.3.5.2 Effect Size

With the increasing push for effect sizes to be published in papers submitted for publication (American Psychological Association, 2001), there has been a need to consider methods of calculating effect sizes for single case research in addition to visual analysis (Olive & Franco, 2008). This allows interpretation and comparison of intervention effect sizes in single subject studies. Calculation of effect sizes, in addition to visual analysis, can produce standardised and reliable results which can support the evidence-base (Vannest & Ninci, 2014). Researchers are now frequently faced with deciding between the vast number of recommended methods for calculating effect sizes in SCEDs (Brossart, Vannest, Davis & Patience, 2014). As the data points presented graphically in single subject research are not independent of each other,

regression analyses are not suitable (Olive & Franco, 2008). Instead there are a number of non-regression approaches which are suggested, each with their own strengths and limitations.

Full descriptions and discussion of the approaches are available (for example, Olive & Franco, 2008; Parker, Vannest, Davis & Sauber, 2011). Several methods including Percentage of Non-Overlapping Data (PND) and Standard Mean Difference (SMD) outlined by Olive and Franco (2008) have been criticised for not accounting for trend in the baseline and intervention phase. Trend in both phases can have significant impact on the interpretations made, as an upward trend in the baseline could suggest improvement despite the intervention, whereas trend in the intervention may represent continuous improvement (Parker et al., 2011). An approach which accounts for trend, reducing the chances of erroneous conclusions being made is the Tau-U effect size analysis, suggested by Parker et al. (2011). Brossart et al. (2014) propose that Tau-U is the most effective calculation of effect size; addressing changes in level and trend, using every data point and being able to handle smaller data sets. For these reasons, Tau-U effect size analysis was chosen.

Benchmarks provided by Cohen (1988) were used to support interpretation of the effect sizes calculated, as they are well known and widely used (Manolov, Jamieson, Evans & Sierra, 2016). According to Cohen (1988), effect sizes above 0.8 are described as 'large', above 0.5 as 'medium' and above 0.2 as 'small'. Effect sizes smaller than 0.2 are described as 'trivial'.

3.4 Qualitative Research Design

Supplementary qualitative data was sought from the supporting adults of the children to explore the implementation factors impacting the outcomes of the study and their perspectives on the outcomes.

Alternative approaches such as questionnaires or focus groups were considered, however interviews allowed the detailed perspective of an individual to be collected. Interviews lend themselves well to being used in combination with other methods such as a case study (Robson & McCartan, 2016). Although mixed methods are more

difficult to execute, they allow broader research questions to be investigated and triangulation from different sources of information (Yin, 2009).

Details of the type of interview used, who was interviewed, and the analysis completed follows.

3.4.1 Semi-structured Interviews

The semi-structured interview is the most commonly used interview type in flexible and mixed methods designs (Robson & McCartan, 2016). They allow specific questions of interest to be asked, in addition to having the flexibility of sequence, wording and time given to each question. The interviewer can change the course of the interview dependent on the responses gained. Semi-structured interviews were therefore deemed most appropriate due to the exploratory nature of the research. Some key historical information was needed in addition to being able to explore the interviewee's experiences and perceptions with flexibility.

3.4.2 Sampling

Each of the facilitators were interviewed, allowing information to be gathered on their role, experience of using tablet-based technology in education, and their perspectives on the implementation and impact of the intervention. In one case, this involved interviewing two supporting adults individually, as both had an equal role in supporting the pupil and implementation of the research.

3.4.3 Interview Procedure

Interviews took place individually, between the researcher and the supporting adult, in a quiet room at the school setting at the end of the intervention. The interview schedule followed can be found in Appendix 8.17. The interviews were recorded on a digital recording device to allow transcription afterwards.

3.4.4 Qualitative Data Analysis

Different types of qualitative analysis were considered including quasi-statistical approaches, thematic analysis and grounded theory (Robson & McCartan, 2016). Thematic analysis was deemed the most suitable for the interview data collected given the supplementary nature of the qualitative data and the time constraints on the researcher. Thematic analysis "is a method for identifying, analysing, and reporting patterns (themes) within data" (Braun & Clarke, 2006, p.6). Thematic analysis fits well

with the pragmatic stance, as it is the most flexible of qualitative analysis approaches which does not make any assumptions on the theoretical or philosophical positioning of the researcher. It is the most commonly used and foundational method of qualitative analysis that is flexible, relatively quick, easy to do and is accessible to people with little experience of qualitative analysis (Braun & Clarke, 2006). It is a useful way of summarising a large amount of data.

Braun & Clarke (2006) outline a six-step process to thematic analysis that was followed. With the qualitative and flexible approach of thematic analysis, these stages are not prescriptive and linear but more of a guidance of the processes involved. The stages are summarised below:

1. Familiarising yourself with data – the initial stage involved accurate transcription of the data from spoken to written text. Further immersion in the data was then achieved by reading and re-reading the data, making note of any ideas and thoughts in the process.
2. Generating initial codes – the researcher coded all the data in a systematic method, identifying all the data relevant to each code.
3. Searching for themes – the codes identified in the previous stage were then arranged into different themes and subthemes. Visual representations were used to help sort the codes into themes.
4. Reviewing themes – The themes were then reviewed and refined to ensure that the theme was an accurate reflection of the codes within it and that the themes reflected the data.
5. Defining and naming the themes – Each theme was defined by identifying what each theme is about and outlining a clear definition.
6. Producing the report – the final stage involved producing a written analysis of the thematic analysis and relating it back to the research questions. Extracts are included in the narrative to form a clear story of the data collected.

3.4.5 Ensuring credibility of qualitative analysis

Qualitative research can be criticised for lack of rigor and the notion of 'anything goes'. However, criteria for good quality qualitative research and analysis has been published. Braun and Clarke (2006) present a checklist of criteria under the headings of

five different stages of the process. Table 3-4 outlines the actions undertaken in each stage to ensure credibility of the thematic analysis undertaken.

Process (taken from Braun & Clarke, 2006)	Steps taken to ensure credibility
Transcription	Transcripts were checked against recordings after completion.
Coding	Extracts from raw data to show trail between spoken voice and interpretations made. Themes refined and checked throughout thematic analysis process.
Analysis	A clear chain of evidence is presented for the process of thematic analysis. Regular supervision was used throughout the analysis stage
Overall	Considerable time given to each stage of the process and supervision used regularly.
Written report	Position of researcher made clear and the influence it may have had on interpretations. Consistency between described method and reported analysis.

Table 3-4: Steps taken to ensure credibility during each stage of Thematic Analysis

3.5 Reliability and Validity

As with all research designs, it is important that steps are taken to ensure that the research is trustworthy, credible and dependable (Yin, 2009). In the following section, the actions and steps taken to improve the reliability and validity of the research are outlined, recognising where limitations remain despite best efforts. Applied research in school settings comes with its own challenges in comparison to highly controlled laboratory-based experiments, although "as long as there is a clear understanding of research ownership, accountability, independence and the roles of all involved from the outset, a lot of these can be mitigated" (Robson & McCartan, 2016, p.12).

3.5.1 Internal Validity

Internal validity is the extent to which any change observed in the dependent variable can be explained by the independent variable (Robson & McCartan, 2016). For causality to be inferred, researchers must acknowledge whether there are any other variables which may be able to explain the change in the dependent variable seen.

The internal validity of the research was strengthened by the addition of the SCED to each of the case studies. SCEDs reduce the threats to internal validity by systematically manipulating the independent variable and taking repeated measures over time across different phases (Kratochwill et al., 2013). Although the simple A-B SCED used in this research has poorer internal validity in comparison to other SCED designs (Barlow et al., 2009), for the reasons outlined in Section 3.3.1 it was judged the most appropriate. Poor internal validity is acknowledged although, several actions were taken to minimise the impact of potential threats. Using the threats to internal validity described by Robson & McCartan (2016), Table 3-5 outlines the actions taken to reduce their impact.

Threats to internal validity	Design considerations
History ***The risk of other things changing in the participants environments other than the intervention.***	Parents and school were asked to keep all other teaching methods and delivery the same throughout.
Testing ***Practice and experience gained on assessments used.***	Four probes were made for each individual testing the same skill, probes presented to students in a randomized order to reduce practice effects. SENT-R used for pre and post assessment had two versions to reduce practice effects.
Instrumentation ***Changes to the way measurements were taken.***	Observations and measurements were taken by the same person throughout the research, where possible according to agreed schedules. In one school where two supporting adults had to be involved due to their working days, the two members of staff were trained together and were in regular communication.
Mortality ***The risk of participants dropping out during the research.***	The researcher maintained regular contact with schools throughout to offer support and encouragement.
Maturation ***Participants growth, change or development that is unrelated to the intervention.***	A baseline period of 3 weeks allowing the researcher to establish a normal trend of movement. Visual analysis techniques used to predict trends.
Compensatory Rivalry ***Improvement in performance by the organization in other areas as a result of being part of the research.***	This is a recognised limitation, that as a result of taking part of the research, schools may have put in extra effort with maths teaching. Inclusion criteria did ensure that the app was the only targeted intervention being experienced by the participant.

Table 3-5: Actions taken by the researcher to address threats to the Internal Validity

3.5.1.1 Intervention Fidelity

To monitor the implementation of the intervention, the TA was asked to keep a daily log to record whether the intervention session was completed each day. Two intervention fidelity checks were completed during the intervention to monitor whether the intervention was being used and accessed as planned and explained in the training session (Section 4.6).

3.5.2 External Validity

External Validity, also often referred to as generalisability, is the ability to generalise the results beyond the specific situation. High levels of external validity were not the primary concern of this research, as the exploratory single case research did not intend to use a representative sample, but rather understand what the impact and accessibility of the app was for the individual (Robson & McCartan, 2016). The more "we learn about the effects of a treatment on different individuals, in different settings…the easier it will be to determine if that treatment will be effective with the next individual" (Barlow et al., 2009, p.46). Users of the SCED argue that external validity can be improved, as here, with the direct replication of the experiment with similar individuals. Detailed information regarding the individual and setting is important to ensure that the context of the case study is clear. Barlow et al. (2009) suggest that two or three cases is sufficient to provide 'literal replication' of the findings.

3.5.3 Reliability

Reliability is the ability for the experiment and data to be replicated, including the stability and consistency with which something is measured. It is the responsibility of the researcher to minimise errors and biases in a study to improve the reliability (Yin, 2009). An essential first step to ensuring reliability is the clear documentation of the procedure (provided here in Chapter 3) to enable another researcher to conduct the same piece of research. The main measurement devices which affect the reliability are the repeated measure of engagement using the structured observation and the pre/post measurements. These will be discussed individually next.

3.5.3.1 Reliability of Repeated Measures

The structured observation that was completed by the facilitator, recording whether the pupil was engaged in the task presented, poses several threats to reliability. This

included ‘Observer Drift’, describing any changes in the way the facilitator used the schedule during the research. For example, becoming more familiar with it (Robson & McCartan, 2016). There was also risks of ‘expectancy effects’ as the facilitator was aware of the intervention commencing and may expect the positive changes (Robson & McCartan, 2016). As it was not possible to have ‘blind observers’, these effects remain a limitation. However, inter-observer agreement (IOA), the extent to which two observers get the same result, is an established method of measuring the reliability of observational schedules. In order to calculate IOA, joint observations were completed between the facilitator and the researcher for each case completed. Due to practical and time constraints, the completion of IOA for 15% of the sessions, suggested by Friman (2009), was aimed for (Section 4.7).

3.5.3.2 Reliability of pre and post measurements

The pre and post measurements of maths attainment, language and executive functioning were used as supplementary data providing insight into the individual’s level of functioning and to triangulate information with the repeated measures. The main sources of threat to reliability were observer bias and error (Robson and McCartan, 2016). The pre and post assessments were completed following a standardised order and instructions reducing the impact of observer error, the effect of any error made in recording the responses of the individual. The possible impact of observer bias, the bias to demonstrate the effect of the intervention, is acknowledged as it was not possible to complete the measures blind to the phase of the research design.

3.6 ETHICAL CONSIDERATIONS

The research was planned and implemented in accordance with ethical guidelines provided by the British Psychological Society (BPS, 2014) and the Standards of Conduct, Performance and Ethics (Health Care Professions Council, 2012). Approval was sought prior to undertaking the research from the University of Nottingham’s School of Psychology Ethics Committee (Appendix 8.18). A summary of the ethical considerations relevant to this piece of research are outlined below.

Consent – It is essential that valid, informed consent is collected from all those involved in data collection. They should be provided with adequate information in

order to give free consent to the process, understanding their data will be kept confidential and of their right to withdraw (BPS, 2014). Informed consent was gained from the Headteacher and SENCo (Appendix 8.11), Supporting Adult (Appendix 8.14) and Parents (Appendix 8.12) in advance of implementation. The initial meeting informed them of the purpose and process of the research. It is an expectation that children are also explained what will happen and given an explicit choice to take part (Robson and McCartan, 2016). Upon meeting the pupil for the first time consent was sought from the pupil in a child friendly way (Appendix 8.15). To suit the needs of the individual this was done verbally, with the written support of the children's consent form where appropriate. Due to the vulnerability of the sample, their assent was "regularly monitored by sensitive attention to any signs, verbal or non-verbal, that they are not wholly willing to continue with the data collection" (BPS, 2014, p.17).

Confidentiality – All information or data collected from a participant must be kept confidential in research unless otherwise agreed (BPS, 2014). Details should not identifiable to a person in any final write-up. Permission was sought from parents to be able to share each pupil's assessment data with the school staff. This was the only information shared in the process; beyond this, all data was fully anonymised, and children were given pseudonyms. Paper data was stored securely at the placement office of the researcher and shredded once inputted to a password protected document. Audio recordings, on the digital recording device, of the interviews with TAs were stored securely at the placement office of the researcher. The recordings were transcribed onto a password protected document, at which point the audio recordings were deleted from the digital recording device.

Respect and Responsibility – With the understanding of moral rights and the responsibility to act in a beneficial way for the participants, children did not miss structured numeracy teaching time. In collaboration with school an alternative time was found, in order to have a minimum impact on the learning opportunities being missed. Ethical consideration was at the fore with the choice of design to ensure that the maths apps was not withdrawn, and schools were left with full access to the apps upon completion of the research.

Risk – Risk is defined by the BPS (2014) as any physical, psychological harm, discomfort or stress caused to participants. As the research involved a vulnerable group of participants, it increased potential to cause harm. However, every action was taken to reduce any potential stress on the participants. The assessments of the participant's maths attainment, language and executive function were terminated if children had shown any signs of upset or distress during the assessment phases. Due to attention difficulties of the participants, play breaks were required and where possible normal structures were followed; for example, using their 'now and next' visual board. Schools and parents were provided with a written summary of the findings after completion, offering to meet if any questions were held (Appendix 8.19).

3.7 Chapter Summary

This chapter positioned the research in the pragmatic paradigm before outlining the decision of using single case methodology, with embedded SCEDs, to explore the impact of the onebillion maths apps on children with DS. Details are also provided of the additional data that was collected through semi-structured interviews with the TAs. Full methodological details are provided including details of the measures used, the procedure and intended data analysis. Issues of reliability and validity are outlined alongside the steps taken to reduce their impact. Finally, the ethical considerations are discussed. The following chapter will provide details of the data collected and subsequent analysis.

4 RESULTS

This chapter presents the results collected from the quantitative and qualitative methods and should be read with reference to the outline of procedure (Section 3.3.4). For each child this includes a description of the child's functioning, the results of the visual analysis of repeated measures within the SCED, for maths attainment and engagement, and pre and post intervention data. Information and pertinent comments from the diary logs kept by the facilitators and their post-intervention interview are presented for each case. Where appropriate, anecdotal information gathered from the TA and observations of the researcher are shared. An interpretative summary is presented for each case.

Following the case studies, the results of the intervention fidelity checks, inter-observer reliability and reliability of visual analysis are presented, to support insight into the reliability of data. Finally, the thematic analysis of qualitative data collected through semi-structured interviews with the facilitators is presented.

4.1 CASE STUDY 1: JIMMY

Age: 7yrs 6mths (at onset of research) **Gender: Male**

Jimmy had a diagnosis of Down's Syndrome. He had corrected vision and wore hearing aids. He attended Year 2 in a mainstream primary school. He had been retained one academic year, and therefore according to his chronological age should be in Year 3. Jimmy had access to an iPad at school and home. Parents reported that Jimmy used the iPad for leisure purposes, with access being described as weekly but not daily. Jimmy's use of the tablet in school was reported to be as a reward following his structured scholastic tasks, often to watch videos or stories.

Jimmy was described by staff as a sociable young boy, who appeared to have poor concentration and was self-directive. On occasions, it was reported by staff that Jimmy was resistant to instructions. A visual timetable and motivators were employed by staff to encourage engagement with learning. His TA shared that due to his audiological difficulties, he often only hears the last part of an instruction. This contributes to his receptive language difficulties which were considerably below age expectations

(Section 4.1.1.3). Language assessment indicated that Jimmy found it difficult to follow two-part instructions. Jimmy was reported to have relatively good expressive language, being able to communicate his wants and needs using short phrases.

4.1.1 Contextual Data

4.1.1.1 Learning Environment

Jimmy was supported by one TA throughout his school day, who worked alongside him in the mainstream classroom and outside the classroom on personalised learning interventions. Jimmy had worked with this TA since the beginning of the academic year, one month prior to the research starting, and therefore the TA recognised she was still getting to know him.

His TA was the facilitator of the intervention in this study, sitting alongside Jimmy providing additional scaffolding and promoting engagement, whilst using the tablet-based app. This work was done outside the classroom, in the corridor space used for small group work and interventions, to reduce distractions and to enable better verbal interaction between Jimmy and his TA. His TA was guided to support Jimmy in remaining on task where needed and to repeat or reword the instructions of the virtual teacher, again, where needed. These approaches followed the usual approaches to Jimmy's pedagogical support.

4.1.1.2 Research Process

Jimmy's was the first case study to be completed and therefore was treated as a pilot study to inform later investigations, focusing upon the pragmatics and utility of the measures planned for this study.

The probe employed for Jimmy, measured his ability to count rationally for numbers one to ten (Appendix 8.20). This was selected based upon consultation with his TA who identified this as an appropriate target skill.

During Jimmy's SCED baseline phase the visual presentation of the probe was adapted as it was deemed by his TA to be hindering his performance because it was too small, and each item was deemed too similar for him to distinguish between them. In collaboration with his TA, the probe was enlarged to A3 in size and the TA used a

cardboard cut-out window as a viewer to move along the page to limit what was on view for him. A significant improvement was seen in his performance after the changes; therefore, the initial accuracy points were removed from the data analysis. These changes happened midway through the baseline phase. Due to one day of absence this meant that only two further baseline measurements were achieved.

Jimmy's engagement with the app intervention was monitored through the structured observations completed by the TA (Appendix 8.7). During the baseline phase these observations of his engagement with maths learning were completed by the TA in the classroom as planned. They continued to be done in the classroom instead of in the intervention area, for two weeks after the intervention was introduced, until the researcher completed an implementation check. Thereafter, observations were changed to focus on Jimmy's use of the app software, as intended. See section 4.1.2.1 for further details.

Jimmy's experience of the intervention across the scheduled 6 weeks was interrupted by a one-week school holiday (Autumn 2018). From the intended 30 sessions of 15-minutes with the app, 83.33% were undertaken. Apart from one absence during the baseline phase, repeated measures were collected twice a week throughout the 9-week research process, giving a total of 17 data points, including 5 baseline points.

4.1.1.3 Predictors

Table 4-1 shows the assessment data gathered regarding Jimmy's level of functioning. Scores were not calculated for the executive functioning task due to difficulties Jimmy had accessing the test.

Test	Scaled Score	Percentile	Description
Comprehension of Instructions (NEPSY-II)	1	0.1	Well below expected level

Table 4-1: Scores from the Comprehension of Instructions subtest from the NEPSY-II for Jimmy

Jimmy's TA completed two questionnaires, the SEND Rating Scale and the Washington questions. The scores are presented in Table 4-2. Higher scores reflect a greater level of difficulty with day-to-day functioning. On the Washington Questionnaire, consisting

of six questions, Jimmy was rated as having 'no difficulty' with his hearing and vision when using hearing aids/glasses. On Question 4, regarding difficulties he may have with remembering or concentrating, Jimmy was described as having 'a lot of difficulty'. On the SEND Rating Scale, Jimmy was rated as having 'moderate difficulty' with learning, memory and attention/concentration.

	SEND Rating Scale (Maximum = 36)	Washington Questions (Maximum = 24)
Scores	17	12

Table 4-2: TAs rating of disability on the SEND Rating Scale and Washington Questions for Jimmy

Overall, Jimmy's low receptive language and highly self-directive nature meant that challenges were faced in the learning environment when structured and adult directed tasks were introduced. Jimmy also had identified difficulties with attention and concentration.

4.1.1.4 App Implementation: Intervention Log and Selected Comments

Jimmy enjoyed learning on the tablet, although required adult support to maintain his attention, and to understand and follow instructions from the virtual teacher. Jimmy accessed a selection of eight different topics from the 'Maths Age 3-5' app, successfully gaining four certificates (Table 4-3). Evidence from the intervention diary log and interview data indicated that Jimmy had found it hard to follow the directions of the virtual teacher, and was self-directed in what he pressed, wanting to play on the same activities repeatedly. Although the app benefits from being self-paced, his TA felt that Jimmy chose an activity he enjoyed and could complete with ease, limiting the learning taking place. Jimmy experienced some frustration when he did not want to follow the instructions within an activity, for example having to move items to a certain place on the screen. His TA suggested that this could be influenced by Jimmy's previous use of the iPad for leisure (reading and games). The TA reported that it was useful to introduce the iPad as an educational resource. It was noted that this enabled time spent on maths learning to be extended. Table 4-3 highlights some key extracts from the raw data pertinent to Jimmy's interaction with the intervention.

Intervention Log – Activities accessed *certificate gained	Log Comments	Pertinent comments from interview [4]
Sorting and Matching* Counting 1-3* Counting 4-6* Where is it? * Lines and Patterns Counting 7-10 Counting 1-10 Adding and taking away	*"Didn't want to follow the instructions" (Week 3)* *"Still only choosing familiar games" (Week 5)* "*A lot of tapping everything randomly" (Week 6)* *"I gave Jimmy less choice today to encourage him to try some different activities" (Week 6)*	"I think he did find it quite frustrating at times" (Line 26) "*He didn't actually want to listen to instructions and do what it was telling you to do. Again, that's the iPad though isn't it, they are so used to them and just being able to do what they want on them."* (Lines 30-31) "*It is getting used to the fact that this is more of an educational tool I think is of benefit to him*" (Lines 108-109) "*he sees me getting the iPad and thinks he is going to get a story*" (Lines 255-256) "*I say it's been a good bridge and when you are trying to keep maths going for a bit longer, it is something he has got enough enjoyment out of to make it worthwhile*" (Lines 266-268)

Table 4-3: A table to show the topics Jimmy accessed from the intervention alongside selected comments from the Diary Log and Interview

[4] Further structured analysis of the data collected from semi structured interventions is presented in Section 4.9

4.1.2 Single Case Experimental Design: Jimmy

4.1.2.1 Engagement

The intervention phase for Jimmy had to be split into two phases because for two weeks after the intervention had been introduced, observations of his engagement continued to be made in normal classroom learning situations (Phase 1). Phase 2 consists of the intended observations of Jimmy's engagement with the intervention. Visual analysis therefore focuses on the change in engagement between the baseline phase and the data collected in Phase 2.

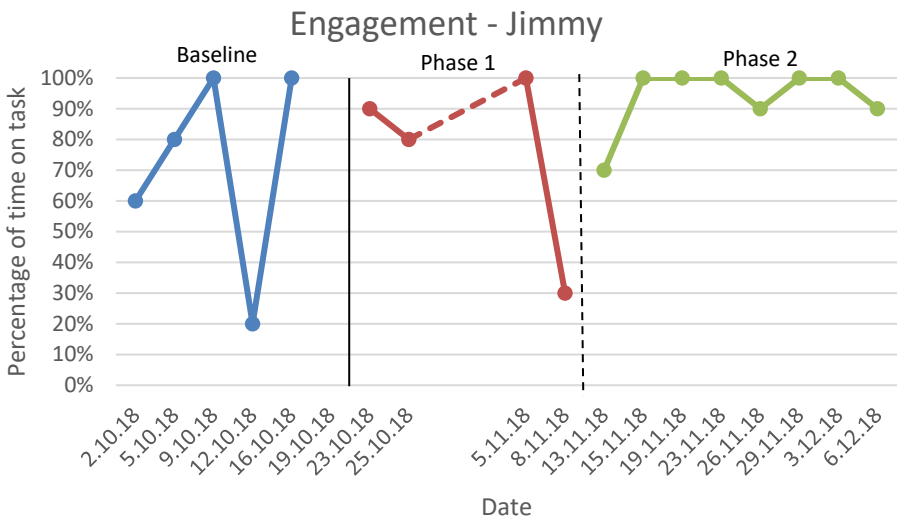
The phases are as follows:

- Baseline – structured observation in normal maths classroom learning
- Phase 1 - Intervention has been introduced however observations remain in normal maths classroom learning
- Phase 2 – Structured observation of Jimmy's engagement with the software.

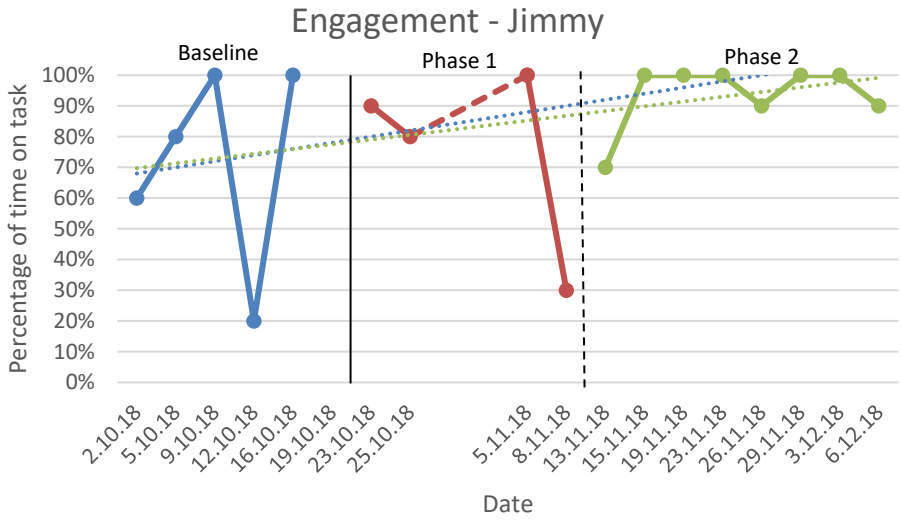
Table 4-4 presents the visual analysis of the graphs 4-1- 4-3.

Feature	Visual Analysis
Level	Mean of the baseline phase: 72% Mean of the Intervention phase (phase 2): 94% Mean level change between phases: difference of 22%
Trend	Slight increase in trend in the baseline phase. Slight increase in trend in phase 2.
Variability	The graph shows large variation in the baseline phase (*range*=80; *SD*=33.47). There is also high variation in intervention phase 2 (*range*=30; *SD*=10.6) however this is smaller than within the baseline phase.
Immediacy of Effect	Within the first three data points of phase 2 there appears to be a significant immediate increase from the baseline phase, which is sustained across subsequent points.
Overlap	All the data points (100%) in phase 2 overlap with the baseline data points.

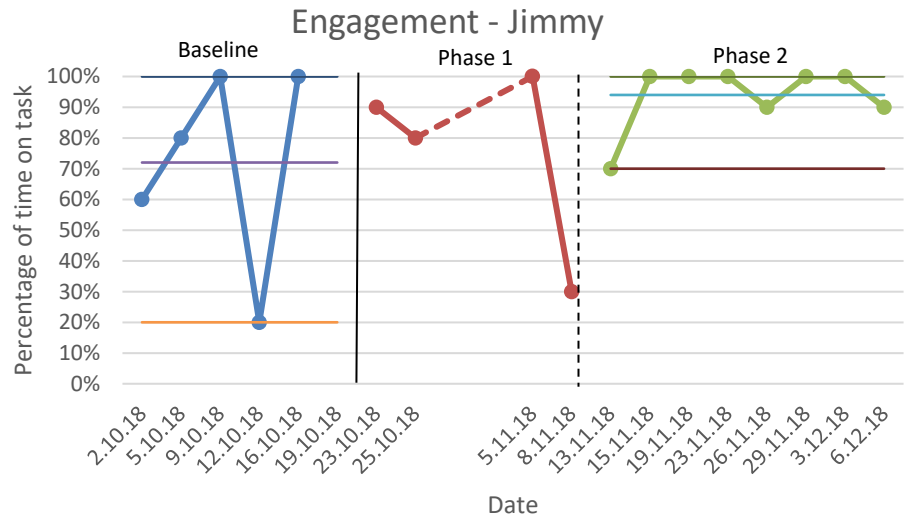
Table 4-4: Summary of the outcomes of the visual analysis for Jimmy's engagement on task



Graph 4-1: A scattergraph to show Jimmy's engagement during baseline and intervention



Graph 4-2: A scattergraph to show Jimmy's engagement with trendlines added.



Graph 4-3: A scattergraph to show Jimmy's engagement with mean lines and variability lines.

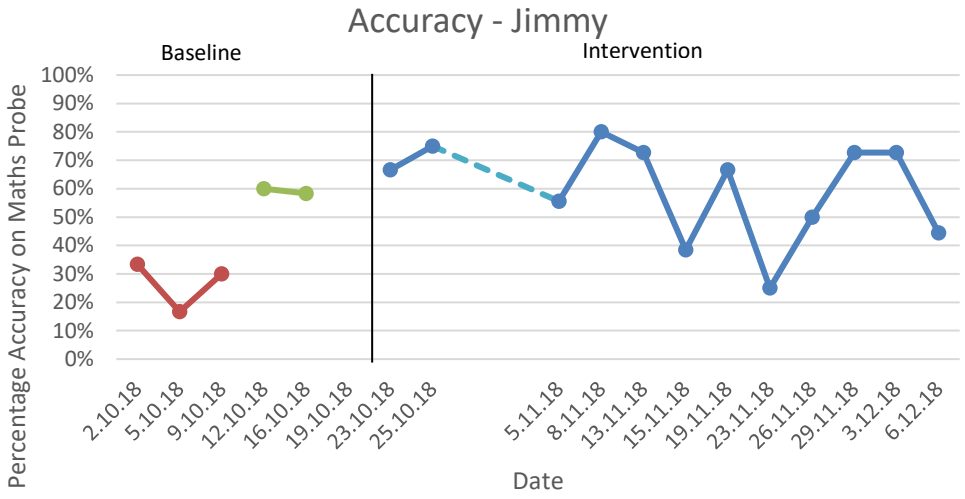
4.1.2.2 Maths Attainment: repeated measures

Target Skill: Rational counting of numbers 1-10

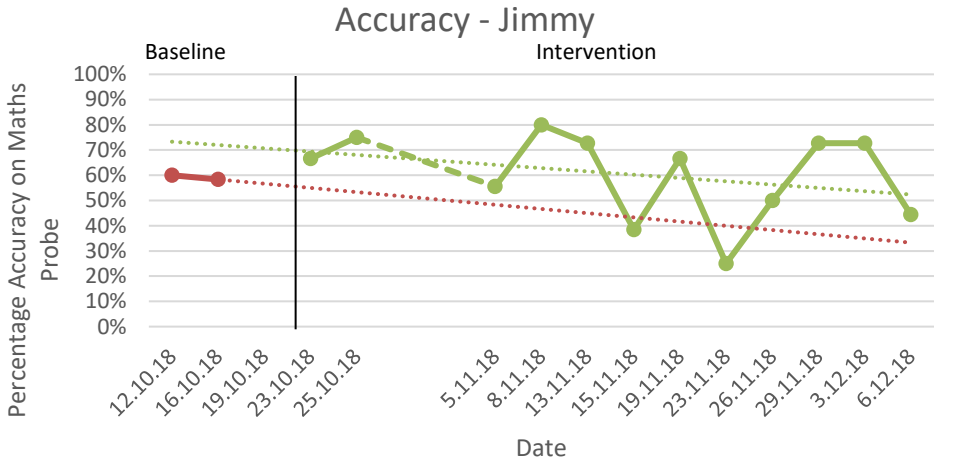
Accuracy on his one-minute maths probe was calculated from the raw data ((number correct/total) x100). Graph 4-4 shows Jimmy's accuracy on the maths probe measuring his ability to rationally count the numbers 1-10. The first three data points from Jimmy's baseline were removed from the visual analysis for reasons explained in Section 4.1.1.2. Trendlines or mean and variability lines are then added (Graphs 4-5 and 4-6). Visual analysis of the graphs can be found in Table 4-5.

Feature	**Visual Analysis**
Level	Mean of the Baseline phase: 59% Mean of the Intervention phase: 60% Mean level change between phases: difference of 1%
Trend	Graph 4.5 shows a slight decrease in the baseline phase. Graph 4.5 shows a slight decrease in the intervention phase.
Variability	Graph 4.6 shows little variation in the baseline phase (*range*=1.67; *SD*=1.18). There is high variability in the intervention phase (*range*=55; *SD*=17.19).
Immediacy of Effect	There is an immediate increase in level following the baseline, however this is not maintained to the third data point.
Overlap	50% of the data points in the intervention phase overlap with data in the baseline phase.

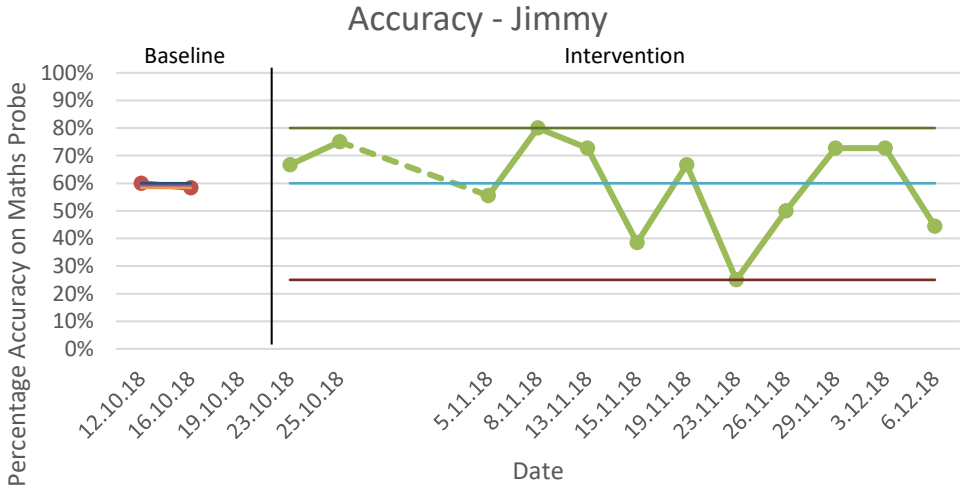
Table 4-5: Summary of outcomes of the visual analysis of Jimmy's maths attainment



Graph 4-4: A Scattergraph to show Jimmy's accuracy on his maths probe across baseline and intervention phase



Graph 4-5: A Scattergraph to show Jimmy's accuracy with trendlines added



Graph 4-6: A Scattergraph to show Jimmy's accuracy with mean lines and variability lines

4.1.2.3 Maths Attainment: Pre and Post Measurements

The results, including the raw score and calculated age equivalent, from the SENT-R (Arnold et al., 2011) administered pre and post intervention can be found in Table 4-6. Jimmy's maths equivalent age was 3 years 5 months behind his chronological age (7:06) at the beginning of the research, however he made 3 months progress by the end of the research period, within 10 weeks. Given the delay evident in Jimmy's maths development, 3 months gain is more than what would be typically predicted.

	Raw Score	Equivalent Age (years: months)
Pre-Intervention	12	4:01
Post-Intervention	14	4:04
Difference	2	0:03

Table 4-6: A table to show Jimmy's performance on the SENT-R pre and post intervention

4.1.2.4 Tau-U Effect Size Analysis

Effect size was calculated for both dependent variables in the repeated measures, see Appendix 8.21 for the output. Table 4-7 shows the effect size, confidence intervals and significance.

	Tau-U Effect Size (2d.p)	Confidence Interval (90%)	P-Value (2d.p)
Maths Attainment	0.17	-0.58< >0.92	0.72
Engagement	0.4	-0.16< >0.96	0.24

Table 4-7: Output from Tau-U effect size analysis for Jimmy (including confidence intervals and p-values)

4.1.3 Interpretative Summary of Jimmy's data

Jimmy worked alongside his TA to access the intervention daily for periods of fifteen minutes in a quiet environment. Having previously predominantly used the iPad for leisure, the use of it as an educational tool was new to Jimmy. His maths and language skills were significantly low in comparison to age expectations. This could provide some explanation for the information from the diary log indicating Jimmy found it difficult to listen to the verbal instructions provided by the virtual teacher, and to inhibit his impulses. His impulses led him to press anything which interested him on

the screen, regardless of what was being asked. Although Jimmy appeared to find some aspects of the intervention frustrating, qualitative data from the TA suggested it has been a useful experience, introducing technology as an educational resource and extending his time learning maths. Intentions were to continue to use the apps with Jimmy.

Engagement

The visual analysis suggests a positive change in Jimmy's engagement in learning when using the app software. There was a desired mean level increase (+22%) between the baseline and intervention phase (phase 2) of the SCED data, in addition to significantly less variance in the intervention phase. However, there are factors which make the conclusions more difficult to make including the large variability in the baseline phase and 100% overlap of data between phases (Kratochwill et al., 2013). The Tau-U effect size analysis indicated a small effect size (*Tau-U*=0.4).

Maths Attainment

The visual analysis indicates no overall effect of the intervention on Jimmy's maths attainment, as measured by the repeated measures (Section 4.1.2.2), with a very small change in the mean performance (+1%). Although 50% of the data points in the intervention phase were higher than the maximum reached in the baseline, conclusions are limited by the large variation in performance during the intervention phase (*range*=55; *SD*=17.19). Tau-U analysis produced an effect size of 0.17 suggesting a 'trivial' sized change (Cohen, 1988). However, the value that can be given to low effect sizes will be discussed in Chapter 5. Pre and post intervention data suggests a positive change in Jimmy's maths attainment, a three-month gain to his maths equivalent age. Whilst, causal inferences must only be cautiously drawn, this progress was encouraging, representing a significant gain both in terms of actual chronological age, and in terms of practical gains for Jimmy in a short period of time.

Conclusion

Overall, the data from the diary log and interview indicates that with TA support Jimmy was able to enjoy learning on the app. Qualitative data suggests that the intervention was found to be useful and will be continued to be used. With the methodological

difficulties experienced, the conclusions regarding its impact on his learning are cautious. The data does indicate a small, practically significant, positive impact on Jimmy's engagement with maths learning (22 mean shift). Impact on Jimmy's maths attainment appears, from the pre and post measurements to be positive. Although, the data from the repeated measures can be judged as more equivocal. Interpretations are discussed further in the subsequent chapter, including consideration that the short intervention period restricted the size of the observable effect.

4.2 CASE STUDY 2: BOBBIE

Age: 6yrs 11mths (at onset of research) **Gender: Male**

Bobbie had a diagnosis of DS. He had corrected vision and wore hearing aids. Bobbie's hearing aid changed during the research process, and staff reported a noticeable improvement in his hearing. Bobbie attended Year 2 in a mainstream primary school with a Resource Provision (RP). Bobbie spent the mornings in the RP, and his afternoons in the mainstream classroom. Core skills were taught in the morning, within a small group of six students with additional needs and a high adult to child ratio.

Bobbie was described as having access to an iPad at school and at home every other day. He used it for leisure and educational purposes in both settings and was described as good with technology. In school his TA shared that the tablet was often used to boost or reinforce a topic taught in the classroom, however this was more frequently literacy based than numeracy.

Bobbie was reported to have a positive attitude to learning, following guidance and instructions from adults well, being able to work well for a reasonable length of time. Bobbie had difficulties with his receptive language and adults supporting him often used gestural sign to support his understanding. Bobbie's expressive language skills were stronger than his receptive language skills, able to communicate his needs to adults with short phrases.

4.2.1 Contextual Data

4.2.1.1 Learning Environment

Bobbie was supported by his TA for all but one hour of his school day. He had worked closely alongside her since he was in Reception and had established a good relationship. His TA facilitated the intervention every morning, completed in the quiet environment of the school's staffroom to minimise distraction from others. Bobbie was understood to like routine and his TA believed the staffroom had no existing associations which may interfere with his engagement with the intervention, i.e. choosing not to use a room already used for speech and language intervention. Before Bobbie's hearing aid was changed, he had used headphones with the tablet

intervention, which his TA said had improved his attention and listening of the virtual teacher. He worked largely independently with the intervention, only occasionally needing language support or task scaffolding, for example.

4.2.1.2 Research Process

Bobbie's case study was completed according to the planned methodology (Chapter 3). His baseline phase started at the beginning of November 2018, with his six-week intervention phase interrupted by a two-week school holiday. There was no missing data, with two repeated measures collected each week for the duration of the research; equating to 18 data points, including 6 baseline points. Bobbie received the intervention 22 times over the six-week intervention phase, equating to 73.33% of the 30 intended sessions of 15-minutes.

4.2.1.3 Predictors

Table 4-8 displays the assessment data gathered regarding Bobbie's level of functioning. Although Bobbie's concentration was good, he was unable to name the shapes required to complete the executive functioning task, therefore no scores were calculated.

	Scaled Score	Percentile	Description
Comprehension of Instructions (NEPSY-II)	1	0.1	Well below expected level

Table 4-8: Bobbie's scores from the Comprehension of Instructions subtest of the NEPSY-II

Bobbie's TA completed two questionnaires, see Table 4-9 for scores, where high scores reflect a greater level of difficulty. On the Washington Questions, Bobbie was reported as having 'some difficulty' with hearing and vision when using corrective vision and hearing aids. On the SEND Rating Scale, Bobbie was reported to have 'severe difficulty' with his receptive language and learning skills. Unlike the other cases, Bobbie was reported to have no difficulty with his mobility on the SEND Rating Scale suggesting relatively strong coordination skills.

	SEND Rating Scale (Maximum = 36)	Washington Questions (Maximum = 24)
Scores	17	14

Table 4-9: Bobbie's ratings, reported by his teaching assistant on the SEND Rating Scale and Washington Questions

4.2.1.4 App Implementation: Intervention Log and Selected Comments

During the intervention phase, Bobbie accessed six of the activities from the 'Maths Age 3-5' app. The diary log did not indicate that Bobbie gained a certificate in any of these areas during the intervention phase. Bobbie was reported to have thoroughly enjoyed, and not required technological support to access, the app (Table 4-10). Bobbie's TA provided some language support, often using sign, as he had difficulty with the propositional language such as 'inside/outside'. His TA thought that the tasks sometimes progressed quite quickly, with the screen quickly becoming busy with visuals. On occasions, his TA would model how to complete a task. Despite some difficulties with the language and visuals in the app, the TA reported positive results with counting skills. The TA believed Bobbie's understanding of quantity had improved, and Bobbie was taking more time to count accurately. At the close of the intervention phase the TA had full intentions of continuing to use the software with Bobbie and others in the RP.

Intervention Log – Activities accessed *certificate gained	Log Comments	Pertinent comments from interview
Counting to 3 Sorting and Matching Counting 4 to 6 Where is it? Counting to 10 Adding and taking away Comparing	"*Used headphones – much better listening to iPad*" (Week 2) *"Still being silly with repeat button." (Week 3)* *"Found the language tricky" (Week 4)* *"Getting better at self-correcting, recounting" (Week 4)* *"Still a lot of guessing" (Week 6)*	"*Well if you mark it out of 10, 10. He has enjoyed it."* (Line 45) "*He was like, he actually wanted to do it so… there was no getting house points if you do this, it was not a chore. He enjoyed it. I enjoyed it*." (Lines 249-251) "*The chance, the option to go over and over it, just because he got a star didn't mean you couldn't go back and do it again*" (Lines 88-89) *"headphones worked better because he looked for less visual clues from me and listened to the programme*" (Lines 79-80) "*I think it was user-friendly. It didn't require much for me as an adult*" (Line 61) "*I'm definitely going to continue it…"* (Line 289)

Table 4-10: A table to show the topics Bobbie accessed from the intervention alongside selected comments from the Diary Log and Interview

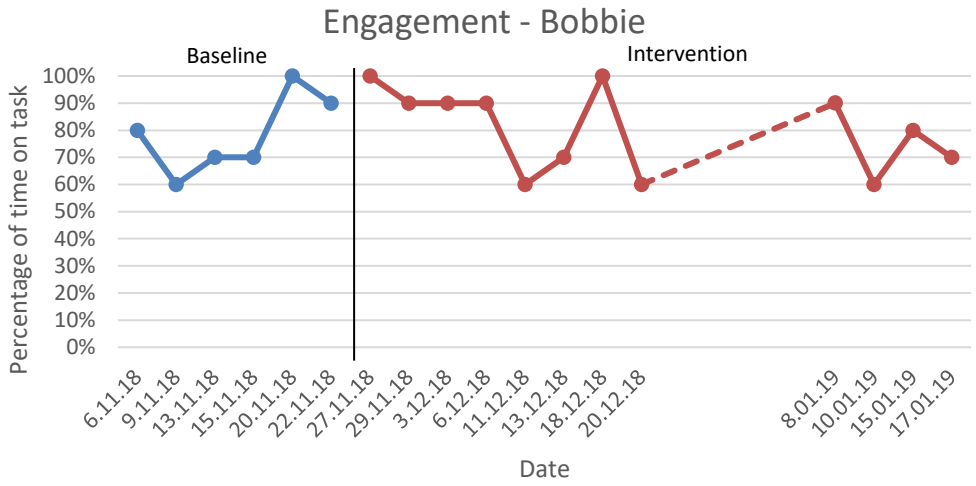
4.2.2 Single Case Experimental Design: Bobbie

4.2.2.1 Engagement

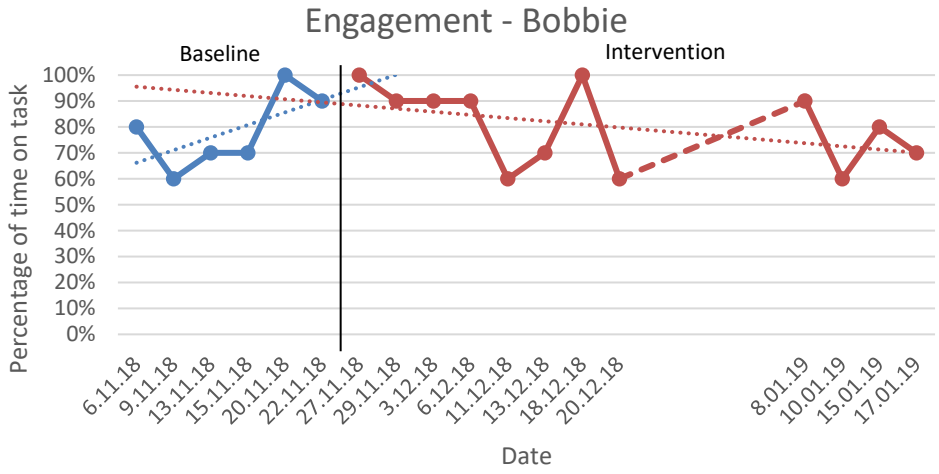
Results from observations of Bobbie's engagement with maths learning, measured by the percentage of time spent on task, during the baseline and intervention phase are shown visually in Graphs 4-7- 4-9. See Table 4-11 for the visual analysis.

Feature	**Visual Analysis**
Level	Mean of the baseline phase: 78% Mean of the Intervention phase: 80% Mean level change between phases: difference of 2%
Trend	Graph 4.8 shows a steep increase in trend in the baseline phase. Graph 4.8 shows a decrease in the intervention phase
Variability	Graph 4.9 shows high variation in the baseline phase (*range*=40; *SD*=14.7). There is also high variability in the intervention phase (*range*=40; *SD*=15.3).
Immediacy of Effect	There is no immediate change in level following the baseline.
Overlap	100% of the data points in the intervention phase overlap with data in the baseline phase.

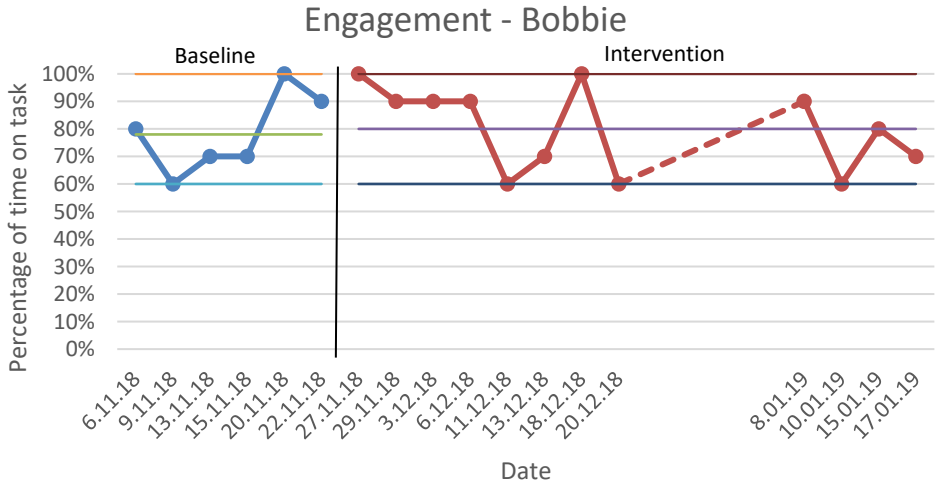
Table 4-11: Summary of outcomes from the visual analysis of Bobbie's engagement with maths learning



Graph 4-7: A Scattergraph of Bobbie's engagement across the baseline and intervention phase



Graph 4-8: A Scattergraph of Bobbie's engagement with trendlines.



Graph 4-9: A Scattergraph of Bobbie's engagement with mean lines and variability lines.

4.2.2.2 Maths Attainment: repeated measures

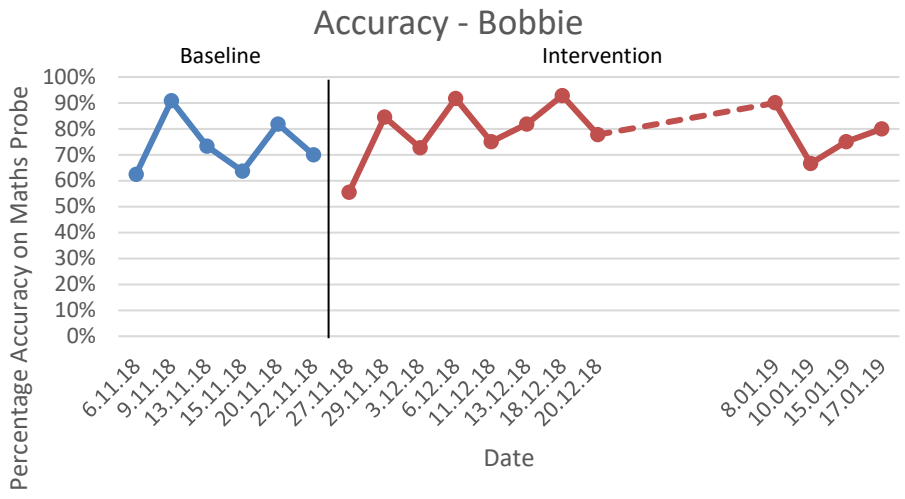
Target Skill: Rational Counting Numbers 1-5

Bobbie's maths probe was an assessment of his ability to rationally count, assigning a number to the objects counted, for numbers one to five. Bobbie's probe (Appendix 8.22) was presented in A3 size to aid its accessibility. Colour was used to distinguish between the items and to increase Bobbie's motivation.

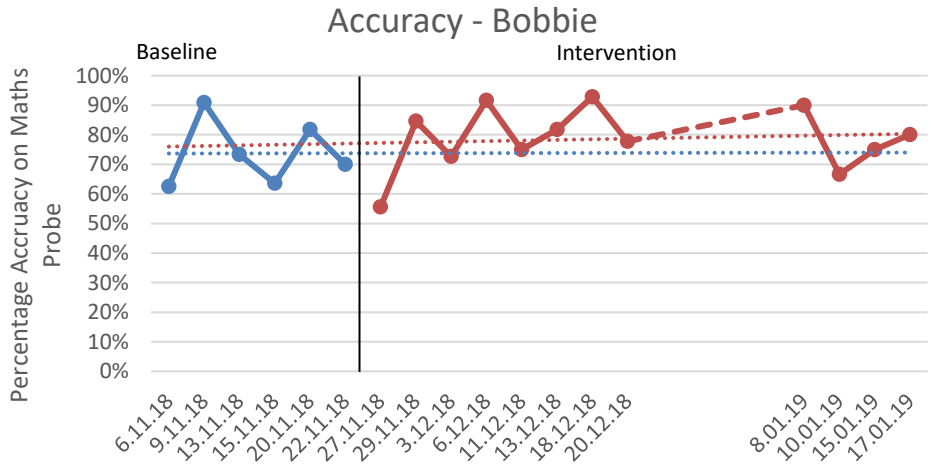
The data is shown graphically in Graph 4-10, with trendlines added (Graph 4-11) and mean and variability lines (Graph 4-12). See Table 4-12 for the visual analysis.

Feature	**Visual Analysis**
Level	Mean of the baseline phase: 73.70% Mean of the Intervention phase: 78.63% Mean level change between phases: difference of 4.93%
Trend	Graph 4.11 shows a stable trend in the baseline phase. Graph 4.11 shows a slight increase in the intervention phase
Variability	Graph 4.12 shows high variation in the baseline phase (*range*=28.4; *SD*=10.9). There is also high variability in the intervention phase (*range*=37.3; *SD*=10.8).
Immediacy of Effect	There is no immediate change in level following the baseline.
Overlap	83.33% of the data points in the intervention phase overlap with data in the baseline phase.

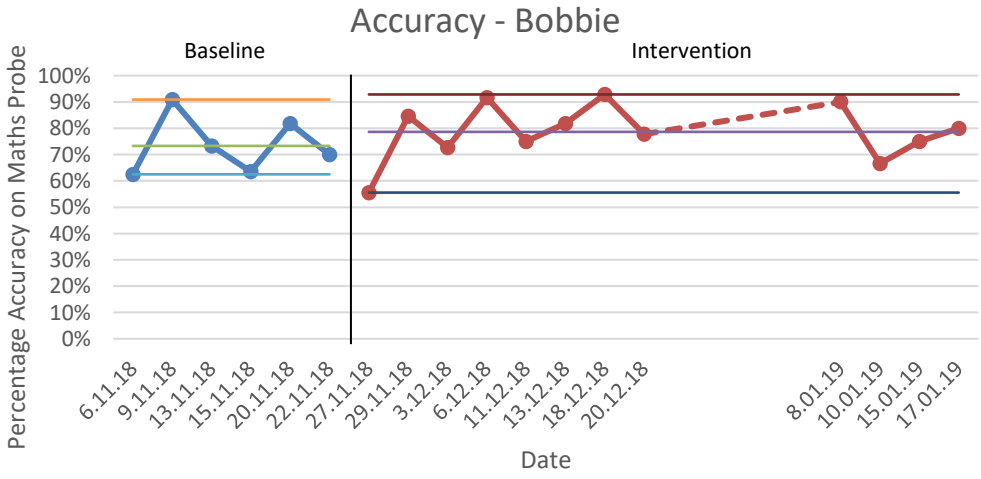
Table 4-12: Summary of outcomes of the visual analysis of Bobbie's maths attainment



Graph 4-10: A Scattergraph of Bobbie's accuracy during the baseline and intervention phase



Graph 4-11: A Scattergraph of Bobbie's accuracy with trendlines added



Graph 4-12: A Scattergraph of Bobbie's accuracy with mean lines and variability lines

4.2.2.3 Maths Attainment: pre and post measurements

Bobbie's results from the SENT-R (Arnold et al., 2011), completed both pre and post intervention are shown in Table 4-13. Bobbie's maths equivalent age was 3 years 3 months behind his chronological age (6:11), making 2 months progress during the research process (11 weeks inclusive of school holidays). As will be discussed in Chapter 5, this improvement is a positive gain considering his significant delay.

	Raw Score	Equivalent Age (years: months)
Pre-Intervention	6	3:08
Post-Intervention	9	4:00
Difference	3	0:02

Table 4-13: A table to show Bobbie's performance on the SENT-R pre and post intervention.

4.2.2.4 Tau-U Effect Size Analysis

Tau-U effect size was calculated for both repeated measures from the SCED (Table 4-14).

	Tau-U Effect Size (2d.p)	Confidence Interval (90%)	P-Value (2d.p)
Maths Attainment	0.32	-0.17< >0.81	0.28
Engagement	0.06	-0.48< >0.54	0.85

Table 4-14: Output from Tau-U effect size analysis for Bobbie (including confidence intervals and p-values)

4.2.3 Interpretative Summary of Bobbie's data

The intervention was delivered by Bobbie's TA for 15 minutes a day in a quiet environment. Bobbie required little technological support, navigating around the app independently, which is likely to be influenced by Bobbie's experience of technology and previous use of it for educational purposes. At the start of the study, Bobbie's maths and language skills were low in comparison to age-related expectations. His positive attitude to learning and ability to focus on a task when working on a 1:1 basis with an adult appears to have allowed Bobbie to successfully engage with the app and demonstrate positive learning gains from the intervention.

Engagement

The visual analysis of repeated measures of Bobbie's engagement with maths learning indicated no significant change, consistent with the Tau-U effect size of 0.06 calculated from these repeated measures (Table 4-14). According to Cohen (1988) effect sizes <0.2 could be described as trivial. Both baseline and intervention phases have large variation in the data and there is 100% overlap of the data between phases. According to the trendlines, it suggests that Bobbie's engagement with the app may have been declining, however this is likely to be influenced by the large variance in the data.

Maths Attainment

The visual analysis of repeated measures suggests a positive change in Bobbie's ability to count his numbers one to five, although the change is small (mean level +4.93%). The trendlines and mean level in both phases, indicate a small change in the desired direction. Firm conclusions are threatened as there was large variability in both phases and furthermore, difficulties establishing a stable baseline. The Tau-U effect size analysis of repeated measures also indicated an effect size of 0.32 for maths attainment, a figure that can be described as small, but significant, particularly in the time period for this study. If the second data point from the baseline phase was removed as an outlier, being considerably higher than others, this effect size is likely to have been greater. The pre and post intervention assessment of Bobbie's maths attainment, demonstrates a two-month improvement in his maths equivalent age, also supporting the conclusion that there is a small increase in Bobbie's maths attainment. This was triangulated with information shared by Bobbie's TA that he was counting more accurately and taking greater care when counting.

Conclusion

Overall, the data suggests that the intervention was a positive learning experience for Bobbie, who enjoyed his interaction with the software when working alongside his TA. Adult support was needed given Bobbie's significant difficulties with receptive language and possibly his hearing to repeat and explain instructions, often using sign. Bobbie's engagement with the app, observed through engagement measures, does

not appear to be any different to his engagement with normal maths learning. This could be accounted for by Bobbie's high engagement with most learning activities and his normal learning environment, which had a high adult to child ratio.

The visual analysis of Bobbie's maths attainment on the repeated measures, supported by the pre and post measurements from the SENT-R (Arnold et al., 2011) and TA perceptions, indicates a positive effect on Bobbie's maths attainment. Greater effects would be expected if exposure to the intervention would have been increased and continued for a greater length of time.

4.3 CASE STUDY 3: MILLIE

Age: 7yrs 7mths (at onset of research) **Gender: Female**

Millie had a diagnosis of DS. She had corrected vision and hearing aids. Millie attended Year 2 in a mainstream primary school with an RP. Millie had been age-retained one academic year and therefore according to her chronological age she should be in Year 3. Although the school had an RP, Millie was educated in a mainstream classroom with 1:1 support. Millie accessed facilities such as the sensory room the RP provided at times when she was unable to manage the mainstream classroom. Her curriculum was also flexible including sensory play and life skill teaching. For example, activities such as going to the park, horse riding and to a cafe were built into Millie's week to learn social skills and promoting safety in the community.

At home, she was described as having access to an iPad most days, predominantly for leisure with some educational activities. In school, the iPad was not used frequently, occasionally being used to watch videos as a break.

Millie had significant difficulties with her receptive and expressive language. School staff were using a total communication approach including symbols and sign. Instructions were kept to 2-3 key words. Millie's speech sounds were also delayed meaning it was difficult to understand her expressive speech. In addition to language difficulties, Millie had difficulties with social communication, influencing her interactions with other children and adults. Learning to be with other children was an area her TA identified as needing development. Millie was reported by her TA to be very self-directive, finding it difficult to follow adult direction and follow a formal curriculum. During the research process, her TA noted that Millie was displaying some difficult behaviour and they were finding it difficult to engage her in learning activities. Her day was having to involve high levels of sensory play and her TA was cautious of how Millie would engage with the app. Millie was reported to be enjoying activities such as baking and going to the park during her school day.

4.3.1 Contextual data

4.3.1.1 Learning Environment

Millie was supported by two TAs who each supported her for two and half days a week, consecutively. However, within the first two weeks of the research one TA went absent from work, leaving one TA with sole responsibility, with Millie five days per week. Millie's TA tried to engage her in use of the app both in the classroom and a small quiet room, exploring which environment would work best although, she showed no increase in either environment. Millie engaged with the app three times in the first week of the intervention, however this did not continue. During successful sessions, Millie's TA supported her with high levels of modelling and turn taking with the app (Section 4.3.1.4).

4.3.1.2 Research Process

A flexible approach was taken to the research process with Millie due to difficulties in completing assessments and in accessing the intervention. It was early in the research process (Week 4) when in consultation with the TA, repeated measures were terminated for ethical reasons. Millie was frequently indicating she was not comfortable with engagement, saying "no" or becoming agitated. Opportunities to engage Millie with the app was left to the TA's discretion, gauging whether it was appropriate from how Millie was emotionally each day. During the research process, Millie only had three sessions with the app, equating to 10% of the intended sessions.

4.3.1.3 Predictors

Millie had significant difficulties accessing the formal assessments used, the SENT-R (Arnold et al., 2011) and NEPSY-II (Korkman et al., 2007). Millie found it difficult to follow adult direction and engage in a formal task; easily distracted by the materials being used and not responding to questions asked of her. As it was not possible to follow standardised procedures with Millie, quantitative assessment data regarding Millie's levels of functioning was unable to be gathered.

Questionnaires regarding Millie's SEND and daily functioning were completed by both her TAs (Table 4-15). Ratings indicated 'some difficulty' with hearing and vision. Millie was the only one of the cases who was rated as having 'severe difficulty' with social

interactions, indicative of possible social difficulties not seen in the other cases involved in the research. Millie's ratings on the SEND rating scale were higher than scores reported for Jimmy and Bobbie, who both scored 17 on the scale. This does suggest that Millie's overall presentation and level of functioning as a learner was lower.

	SEND Rating Scale (Maximum = 36)	Washington Questions (Maximum = 24)
Teaching Assistant 1	18	14
Teaching Assistant 2	19	13

Table 4-15: Millie's scores, reported by her teaching assistants on the SEND Rating Scale and Washington Questions

Overall, Millie had a range of complex needs, with observations and ratings indicating some social and emotional difficulties at the time of the research.

4.3.1.4 App Implementation: Intervention Log and Selected Comments

Due to limited engagement with the app, Millie only accessed one topic within the intervention, 'Sorting and Matching'. No quantitative data was collected for Millie. Table 4-16 presents selected comments from the intervention diary log and the interview completed with the TA. Millie's TA was interviewed to capture Millie's story, gather information on the difficulties experienced and the possible factors which had an impact.

During the first week of the intervention being introduced, Millie accessed the app on three occasions. From the diary log kept by her TA, it was evident that Millie required a high level of support, with her TA modelling the activity and taking turns on the app. From comments selected from the interview, it suggests that her TA believed her to be engaged initially (Table 4-16). However, some frustration from Millie was noted in the diary log.

Following this first week Millie did not engage with the app. Her TA reported that Millie was resistant, displaying refusal behaviours. During a visit, the researcher observed Millie saying "no", although Millie watched her TA play on the app for a minute. For professional and ethical reasons, and to prevent Millie becoming agitated engagement was not pushed. During the interview, the TA expressed her views that

with Christmas approaching, there was a high level of environmental activity and loss of routine which she believed was having an adverse impact on Millie and her engagement with learning. Despite these difficulties, the TA shared some intention to try to use the intervention in the future, recognising that it could be useful for Millie given the appropriate activities experienced (Sorting and Matching).

4.3.2 Interpretative Summary of Millie's data

Millie's case has highlighted the difficulties that some children with DS may experience with the intervention. In comparison to other cases involved in the research, Millie was following more of a play-based curriculum and appeared to have greater difficulty engaging with structured, adult-directed learning tasks. Factors including Millie's social and emotional development, and environmental influences, such as the level of external distractions in the school environment, affected her engagement. Individual characteristics and level of need in areas such as language, social and emotional development need to be considered.

Intervention Log – Activities accessed *certificate gained	Log Comments	Pertinent comments from interview
Sorting and Matching	*"Worked with Millie to show her what to do" (Week 1)* *"Picked up quicker today, still a bit tricky with how to put the colour on to the plate, cup etc…" (Week 1)* *"Got frustrated today with program" (Week 1)*	*"I think at the beginning, I think when I started it, I felt as if she was engaged … because she was having a little go at it or I started it first so it was led at first by me, but then she would quite happily do it herself."* (Lines 25-27) "*I think it was a bad time of year as well, I think that played a big part in it because it was on its way to Christmas, there is so much happening in the classroom and we are trying to get her to do our work as well, we are trying to fit that in , and I think that was a big hurdle*." (Lines 80-83) "*Do you know what, I will keep having another try because I think it's quite interesting to be able to use it has a little social because it is still learning for her and it will help her*." (Lines 259-260) ***"R: So, you mentioned that's to do with mood?** C: Definitely, on the day, how she is, and I think it depends on maybe how she has come in. Because that would speak volumes about how much work we would get out of her in the day as well."* (Lines 40-43)

Table 4-16: A table to show the activities that Millie accessed from the intervention alongside key extracts from the diary log and interview.

4.4 CASE STUDY 4: RICHIE

Age: 6yrs 2mths (at onset of research) **Gender: Male**

Richie had a diagnosis of DS. He had corrected vision and hearing aids. Richie was in Year 1 in a mainstream primary school, and the youngest of the four cases involved in the research. Richie was a highly energetic, sociable young boy who had relatively good receptive language, understanding what was happening around him and comprehending instructions. His TAs reported that they were consistent with the language they use, to ensure that for his level, Richie was not taught a number of words which meant the same. Richie struggled with some of the propositional language used by the virtual teacher as he was yet to learn the vocabularly. Richie had poor expressive language; using limited words, often in isolation, and his speech clarity was delayed.

Richie followed adult direction well, particularly from his two TAs who he knew well, showing enthusiasm to tasks presented to him. Attention and concentration were limited, requiring learning tasks to be kept short. Richie was very alert to his environment, easily distracted by things happening around him.

His parents shared that he usually had daily access to an iPad at home, however had recently gone six months without one. Whilst one of his TAs reported very little use of the iPad in school, the other TA reported use of educational apps occasionally.

4.4.1 Contextual Data

4.4.1.1 Learning Environment

Richie was supported by two TAs, one supporting him each morning and another in the afternoons. Both had worked alongside Richie since he had started in Reception, approximately for 18 months. They knew him well and had both established a good relationship with him. In school, Richie responded well to a 'now and next' board, using visual images of different tasks to structure his day. Between short learning activities, he completed an activity of his choice, such as playing with cars, to motivate him and allow a short break. Both Richie's TAs, who had regular contact with each other, were involved in the research process.

Richie's school was a small busy primary school which had limited space for quiet interventions. The intervention therefore took place wherever was possible each day, such as at a table outside the classroom or in an empty ICT suite. The quieter environments worked well for Richie, as he was easily distracted by his surroundings.

4.4.1.2 Research Process

Richie was the last case to be identified for research participation and started the research process in the middle of November 2018. Data collection was interrupted by a two-week school holiday. There was some missing data from the repeated measures, reducing the baseline down to three data points for his engagement with maths learning.

Baseline data for Richie's accuracy on his initial repeated measure assessing number recognition (Appendix 8.23) yielded accuracy rates of 100%. The researcher was not aware to intervene with the probes being used until the last week of baseline measures with the intervention about to start, due to missing data on the first visit. For ethical reasons, it was judged that the intervention should not be withheld, despite him having reached 'ceiling' on the repeated measures. Therefore, a new target skill was measured after one week of the intervention, measuring his ability to count rationally item sets of one to five (Appendix 8.24). This limited the analysis of repeated measures maths accuracy data as no baseline was established.

Richie had 28 out of the intended 30 sessions with the app, equating to 93.33%.

4.4.1.3 Predictors

Table 4-17 shows the assessment data gathered regarding Richie's level of functioning. As with the other participants, results were not obtained for executive functioning due to difficulties accessing the test.

	Scaled Score	Percentile	Description
Comprehension of Instructions (NEPSY-II)	1	0.1	Well below expected level

Table 4-17: Richie's scores from the Comprehension of Instructions Subtest from the NEPSY-II

Both of Richie's TAs completed the questionnaires regarding his level of functioning (Table 4-18 for scores). With hearing aids and glasses, his TAs reported 'no difficulty' with his vision or hearing. Richie was rated as having 'severe difficulty' with his expressive language and 'moderate difficulty' with his learning, memory and attention.

	SEND Rating Scale (Maximum = 36)	Washington Questions (Maximum = 24)
Teaching Assistant 1	19	11
Teaching Assistant 2	20	11

Table 4-18: Richie's teaching assistants reported scores from the SEND Rating Scale and Washington Questions

Overall, Richie's scores on the SEND Rating Scale, indicate the highest level of difficulty out of the four participants in the research. Richie appeared to have greater difficulty with his expressive language and concentration in comparison to Jimmy and Bobbie. On the other hand, Richie did not appear to have the additional social and emotional difficulties experienced by Millie.

4.4.1.4 App Implementation: Intervention Log and Selected Comments

Richie accessed all ten topics within the app 'Maths, age 3-5', gaining certificates in six of them over the course of six weeks. Despite some difficulties with language, Richie was independent with the intervention, requiring little technological support, and was reported to listen well and respond to the virtual teacher. His TAs provided additional explanation of the tasks where necessary, particularly with propositional language, such as in front or behind. As evidenced by the selected comments (Table 4-19), Richie's TAs reported high levels of enjoyment for Richie, describing a very positive learning experience. They reported that Richie had been excited to use the app daily, enjoying the choice of short and colourful activities with immediate feedback. Richie was described as more confident and stronger with his counting. Notably, they had also noticed improvements in his listening and speech skills since using the intervention.

Intervention Log – Activities accessed *certificate gained	Log Comments	Pertinent comments from interviews
Sorting and Matching* Counting to three* Lines and Patterns* Counting 4 to 6* Where is it?* Counting 7 to 10 Patterns and Shapes Counting 1 to 10* Comparing Adding and taking away	*"Session outside the classroom, background noise" (Week 4)* *"Good listening today" (Week 3)* *"Richie loved the shapes -3" (Week 2)* *"Richie found it difficult to understand above and below" (Week 2)* *"Quiet room in the afternoon, Richie had good listening and concentration" (Week 3)*	"He has absolutely loved the app" (D1, Line 28) "…whenever you said "oh Richie we're going to do the maths app" he has got a big smile on his face" (D1, Line 47-48) "I think it's been really helpful, because it's been able to support them, and it links in with all the topics that you are doing in the classroom as well" (D1, Lines 63-64) "It's colourful, it's got short bursts, each activity doesn't last long so it holds his interest. It's very colourful and another side of for me, is that he has to listen to it as well." (D2, Lines 32-33) "I think it has helped him with his listening skills and I think it has helped him with his speaking as well." (D2, Lines 190-191)

Table 4-19: A table to show the activities Richie accessed from the intervention alongside extracts from the diary log and interview.

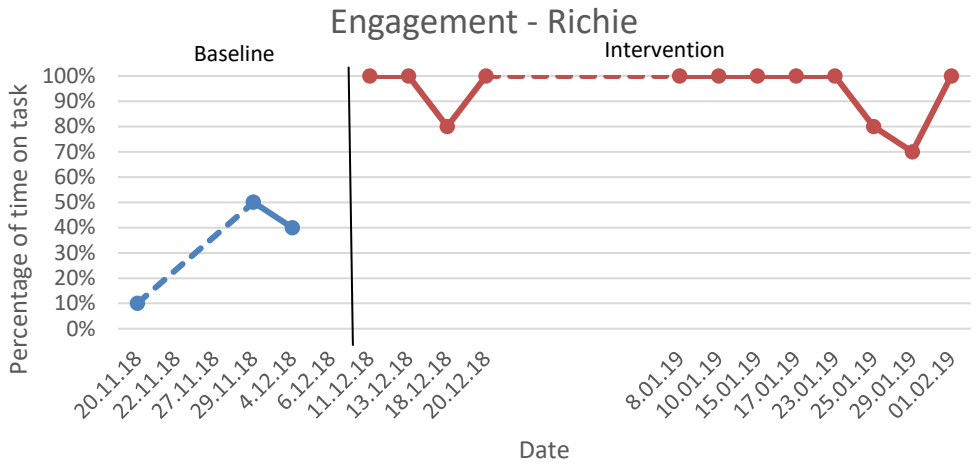
4.4.2 Single Case Experimental Design: Richie

4.4.2.1 Engagement

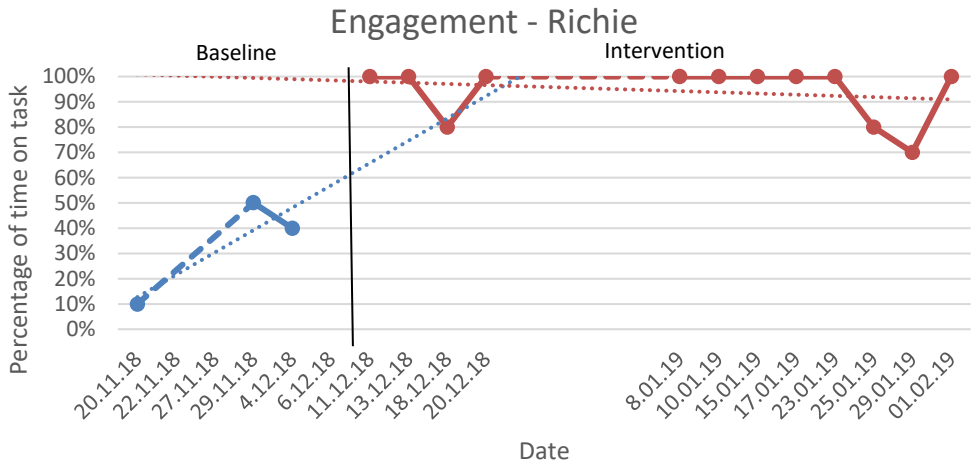
The repeated measures of Richie's engagement with maths learning, using the structured observation (Appendix 8.7) are presented visually in Graphs 4-13-4-15. Although there was missing data for the baseline, the minimum of three data points (Kratochwill et al., 2010) was met. Table 4-20 contains the visual analysis of level, trend, variability, immediacy of effect and overlap.

Feature	**Visual Analysis**
Level	Mean of the baseline phase: 33% Mean of the Intervention phase: 94% Mean level change between phases: difference of 61%
Trend	Graph 4.14 shows a steep increase in trend in the baseline phase. Graph 4.14 shows a decrease in the intervention phase
Variability	The graph shows high variation in the baseline phase (*range*=40; *SD*=20.8). There remains high variability in the intervention phase (*range*=30; *SD*=10.8) however it is smaller than the baseline phase.
Immediacy of Effect	There is an immediate increase in level following the baseline phase, which is sustained across subsequent data points.
Overlap	None (0%) of the data points in the intervention phase overlap with data in the baseline phase.

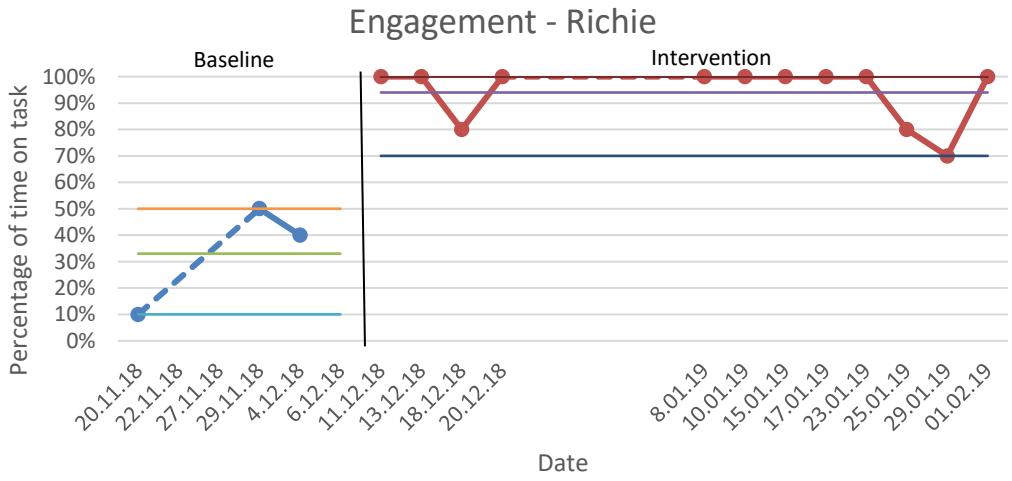
Table 4-20: Summary of the outcomes from the visual analysis of Richie's engagement with maths learning.



Graph 4-13: A Scattergraph of Richie's engagement across the baseline and intervention phase



Graph 4-14: A Scattergraph of Richie's engagement with trendlines added



Graph 4-15: A Scattergraph of Richie's engagement with mean lines and variability lines

4.4.2.2 Maths Attainment: repeated measures

Target skill 1: Number Recognition 1-6

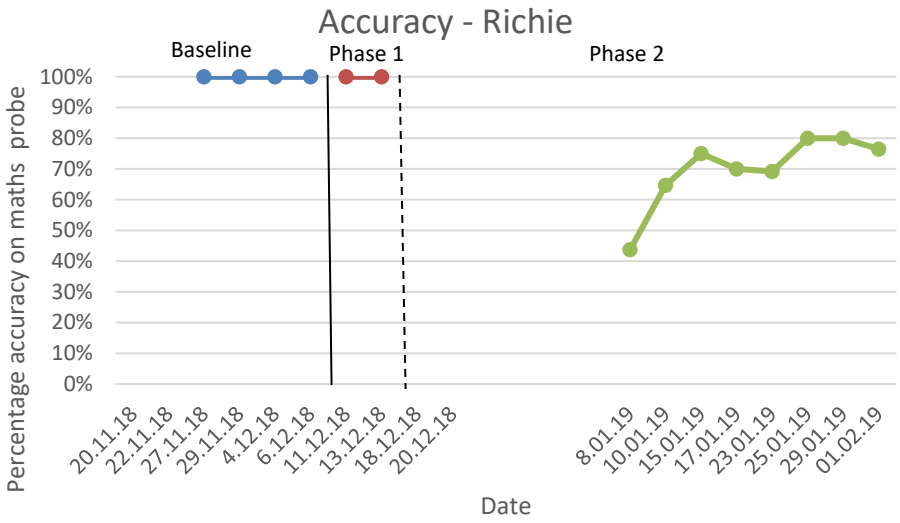
Target skill 2: Rational Counting 1-5

Ceiling effects were experienced in the baseline phase, through the repeated measures (for further details please refer to Section 4.4.1.2). Following initial consultation with staff supporting Richie, a target skill of number recognition was identified however, following the baseline it was evident that Richie was achieving 100% accuracy. Ceiling effects can be seen in the first six data points on Graph 4-16. Unfortunately, due to difficulties experienced by the researcher, this was not recognised until the intervention was due to begin and therefore to prevent the intervention being delayed a higher order skill was introduced a week after the intervention had been introduced. It was important that these two changes were not done at the same time. The target skill was changed to rational counting of numbers one to five.

The details of each phase are summarised below:

- Baseline - Repeated measure of target skill 1 (Number Recognition 1-6)
- Phase 1 - Intervention is introduced, repeated measure of target skill 1 (Number Recognition 1-6)
- Phase 2 - Intervention continues, repeated measure is adapted to target skill 2 (Rational Counting 1-5)

The accuracy of Richie's responding on the maths probe is presented visually in Graph 4-16. As no baseline data was established, visual analysis was not possible. An upward trend on the second target skill (seen in phase 2 of Graph 4-16) is noted, however it is not possible to say whether this was normal maturation or influenced by the intervention. Staff perceptions indicated that Richie had become stronger and more confident with his counting as a result of using the intervention.



Graph 4-16: A scattergraph of Richie's accuracy during the baseline and intervention phase

4.4.2.3 Maths Attainment: pre and post measurements

Richie's raw score and calculated equivalent age from the SENT-R (Arnold et al., 2011), administered both pre and post intervention, are presented in Table 4-21. Richie's maths equivalent age was 2 years 1 month behind his chronological age (6:02). He improved by one month over the research duration, 11 weeks inclusive of school holidays.

	Raw Score	Equivalent Age
Pre-Intervention	12	4:01
Post-Intervention	12	4:02
Difference	0	0:01

Table 4-21: Richie's scores on the SENT-R pre and post intervention

4.4.2.4 Tau-U Effect Size Analysis

	Tau-U Effect Size (2d.p)	Confidence Interval (90%)	P-Value (2d.p)
Engagement	1	0.37< >1	0.01

Table 4-22: Output from Tau-U effect size analysis for Richie (including confidence intervals and p-values)

4.4.3 Interpretative Summary of Richie's Data

Richie accessed the intervention daily (for 15 minutes) for six weeks. Richie's maths and language skills were low in comparison to age expectations, but he was noted to be a responsive learner. Interviews with his TAs indicated that Richie thoroughly enjoyed the intervention, eager to spend time on it. Their perceptions on its impact suggested improvements in his speech, listening and confidence. Richie's verbalisations whilst using the app were reported to have improved, with Richie beginning to verbalise what he was doing whilst interacting with the app. One TA highlighted that these verbalisations had become clearer and he was beginning to use short phrases.

<u>Maths Attainment</u>

Visual analysis was not possible for Richie's maths attainment, limiting conclusions which can be drawn. It is possible, however, to note the positive upward trend during the intervention phase, triangulated with a small difference on the SENT-R (Arnold et

al, 2011). This suggests that if visual analysis, comparing baseline to intervention phases, had been possible a positive effect may have been seen. Triangulation with data from the interviews, also suggests that his TAs perceived Richie to be taking greater care with his counting, slowing himself down and achieving greater accuracy. He was described as more confident with his maths following the intervention.

Engagement

The visual analysis of the repeated measures of Richie's time on task indicates a significant effect of the app on his engagement during the intervention. There is a large positive increase in the mean level between the baseline and intervention phase (mean level increase +61%). Although both phases have a large amount of variability, there is no overlap (0%) between the data in the two phases. It is therefore possible to conclude that Richie experienced significantly greater engagement in maths learning when it was presented on tablet technology. Such conclusion was further supported by the large effect size calculated (*Tau-U*=1). Consistent with these findings, was the high level of engagement reported by his TAs, who indicated that tablet-based learning caught Richie's attention. He benefited from learning in a quiet environment with the short instructions provided by the virtual teacher.

Conclusion

Overall, the results suggest a positive effect on Richie's learning behaviours, demonstrated by the positive effect seen on Richie's engagement with learning maths. Unfortunately, restrictions on data analysis means that the effect on Richie's maths attainment cannot be inferred. His TAs indicated some positive effects on other areas including speech and his listening skills.

4.5 Cross Case Comparison of Predictors

Table 4-23 displays the age of each participant at the start of the research, their maths age equivalent gains and the information that was gathered about their level of functioning. Where two TAs rated an individual's functioning, an average of the two scores is reported here to aid comparison.

	Age at onset (years: months)	Language (Scaled Score, NEPSY-II)	SEND Rating Scale (Max=36)	Washington Questions (Max=24)	Duration in weeks (including school holidays)	Maths Equivalent Age gains (in years: months)
Jimmy	7:06	1	17	12	10	0:03
Bobbie	6:11	1	17	14	11	0:02
Millie	7:07	N/A	18.5	13.5	N/A	N/A
Richie	6:02	1	19.5	11	11	0:01

Table 4-23: Age at onset, language, reported level of functioning and gains in maths for each case.

No statistical analysis was possible; however, relationships can be observed when the data for Millie who did not engage with assessments or the app, is excluded. These are:

- There appeared to be a relationship between age at start of the research, and the maths age equivalent gains on the pre and post measurement of maths attainment. The older the individual at the beginning the larger the gain seen.
- There appeared to be a relationship between the SEND Rating scale score and the improvement in maths. Higher scores (reflecting greater difficulties) are related to smaller gains.
- No relationship was seen with the Washington Questions scores, which suggests that the SEND Rating Scale may be more sensitive and had greater relevance to the educational context of this research.

These observations are made tentatively owing to the selected case study design. Qualitative data, explored below, identified some contribution of individual predisposition to engagement with the app. This suggests that careful measurement and description of SEN requires both sensitivity in measurement and qualitative functional descriptors.

4.6 Intervention Fidelity

Intervention fidelity checks were completed using two methods:

1. Intervention diary logs which allowed the calculation of the number of sessions with the app experienced by the learner.

- Intervention observations which ensured the intervention had taken place as intended. The checklist can be found in Appendix 8.25.

According to the research schedule, it was intended that participants interacted with the app for 15 minutes daily for 6 weeks, meaning a total of 30 sessions. Calculation of the percentage of the intended sessions that had taken place was necessary, recognising the impact of absence or school trips. Table 4-24 shows the percentage of sessions which took place for each case study.

Case Study	Number of sessions which took place:	Percentage of sessions:	Example Reasons provided:
Jimmy	25	83.33%	Inset day, Facilitator absent, Pupil had medical appointments, School trip
Bobbie	22	73.33%	School trip, Christmas activities in school, School holiday, Facilitator absent, Pupil not feeling well, No internet.
Millie	3	10%	Lack of engagement
Richie	28	93.33%	Inset Day

Table 4-24: Details of the number of sessions with the intervention each case experienced, the percentage of the intended sessions this equated to and example reasons for missed sessions provided by the facilitator.

Visits were made to each school to observe the intervention; aiming to complete two implementation checks per school. However, only one was achieved at Bobbie's school. Lack of engagement with the intervention for Millie meant that intervention fidelity checks were not appropriate. The checklist (Appendix 8.25) included three factors, and as can be seen in Table 4-25, intervention fidelity was high. All the pupils were accessing their own profile on the app, either repeating previous activities or starting new ones. TAs were using quiet areas in the school, to enable reduced distraction and allow the necessary support to be provided. The time spent on the intervention was lengthened by five minutes on one occasion as the individual was engaged well.

Feature	**Percentage of sessions observed**
Intervention lasts for 15 minutes	80%
Child accessed their own profile and worked through activities	100%
Intervention was accessed in a quiet environment with adult support	100%

Table 4-25: Intervention Implementation Checks: displaying the percentage of observed sessions which were completed according to researcher's guidance.

4.7 Inter Observer Reliability

Calculating IOA is a recognised method of establishing the reliability of observations (Section 3.5.3.1). Due to logistical and geographical time constraints, the minimum of 15% for joint observations (Friman, 2009) was not reached. However, from the observations that were completed, the percentage agreement indicated a high level of reliability (Table 4-26).

	% of joint observations completed (to 1d.p)	Overall % of agreement (to 1d.p)
Jimmy	11.8%	90%
Bobbie	5.6%	100%
Millie	Not Applicable	
Richie	13.3%	100%

Table 4-26: Results from the inter-observer reliability checks.

4.8 Reliability of Visual Analysis

Acknowledging the subjectivity of visual analysis, inter-rater reliability was calculated. Inter-rater reliability of visual analysis is a procedure used to calculate the degree of certainty that there has been a change in the dependent variable when the intervention is introduced. Using the guidelines presented by Brossart et al. (2006), the researcher and another Trainee Educational Psychologist (TEP) rated the extent to which they agreed with a statement per graph. The context of the research, the graphs created and the tables including the features of the visual analysis, were shared with the other TEP, who was familiar with the visual analysis of SCED data. On a scale of 1 to 5, both rated the extent to which they agreed with a statement where 1 meant 'Not at all certain' and 5 meant 'Very certain'. An example statement used was:

"*There is a significant change in the pupil's accuracy on the maths probe when the intervention is introduced."*

The ratings from the two observers were analysed using linear weighted Cohen's Kappa (Cohen, 1968). Due to an ordinal rating scale being used in the process, the weighted Kappa was used as it accounts for not just the agreement but the distance between ratings (Viera & Garrett, 2005). Appendix 8.26 contains the weighted Kappa output. Interpretations were made according to the guidelines from Viera & Garrett (2005) who suggest that a value smaller than 0.20 indicates a poor level of agreement, between 0.21-0.40 is a fair agreement, 0.41-0.60 is a moderate agreement, 0.61-0.80 equates to substantial agreement and above 0.81 is almost perfect agreement.

Weighted Cohen's Kappa indicated a level of agreement of 0.773, which suggests a substantial agreement between the two observers, further strengthening the reliability of the visual analysis and the conclusions made from it.

4.9 QUALITATIVE DATA

Qualitative data was collected through semi-structured interviews with each pupil's TA, exploring research questions 4 and 5:

4) What were the facilitator's perceptions of the outcomes of tablet-based learning for the children with Down's Syndrome?

5) What factors influence tablet-based learning for children with Down's Syndrome?

Thematic Analysis (Braun & Clarke, 2006) was used to analyse the data collected (see Section 3.4.4 for procedure). Five interview transcripts were analysed, initially coding each transcript, identifying extracts that might be relevant to either of the research questions. Once an initial list of codes for each transcript had been produced, these were cross-referenced to produce a final list of 46 codes (Appendix 8.27). Codes which only appeared in one transcript were removed unless in contradiction to another code. Following the guidelines of thematic analysis (Braun & Clarke, 2006), the codes were grouped into potential themes relevant to the two research questions. Appendix 8.28 presents the audit trial, showing the coded extracts for each theme. Original transcripts and codes were re-examined to ensure that the generated themes were an accurate reflection of the data gathered.

4.9.1 What were the facilitator's perceptions of the outcomes of tablet-based learning for the children with Down's Syndrome?

A thematic map presenting the themes, alongside any contradictions is shown in Figure 4-1. Thematic analysis identified four key themes addressing the question of what the facilitator's perceptions of the outcomes were:

- The intervention was a positive experience for the pupil and facilitator
- The intervention influenced the perception of the use of technology
- Improvements in mathematical knowledge and skills
- Improvements in other learning skills.

Each individual theme will be discussed, with relevant illustrative extracts.

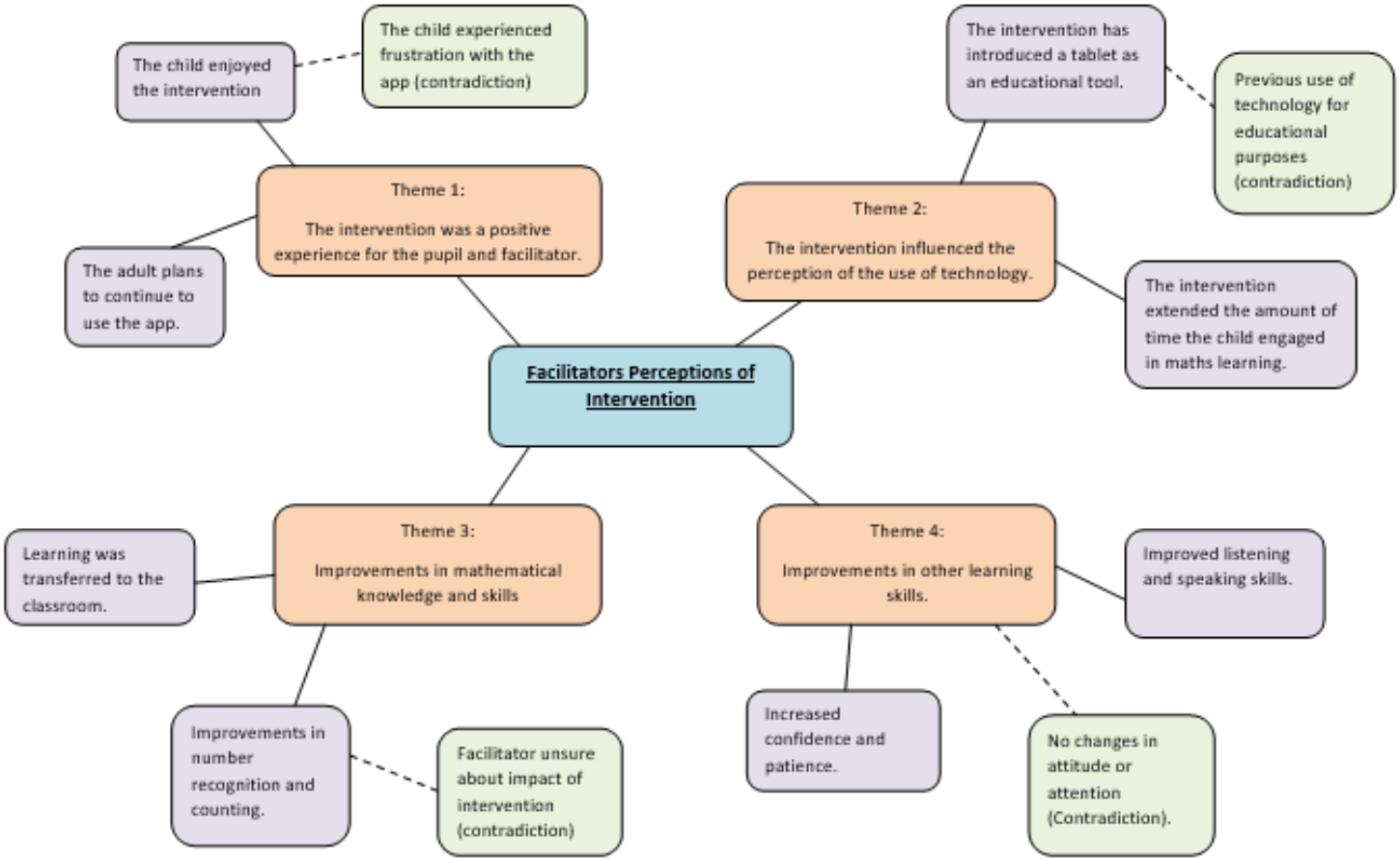


Figure 4-1: Thematic map for research question 4: What were the facilitator's perceptions of the outcomes of tablet-based learning for children with Down's Syndrome?

4.9.1.1 Theme 1: The Intervention was a positive experience for the pupil and facilitator

The facilitators spoke positively about the apps and reported that the pupils had enjoyed learning on them. Richie's TA commented that "*He has absolutely loved the app, we're having to whenever he is on the iPad, we are having to tell him he can't go on the iPad, that app, after he has been on it because he is constantly wanting to press it to play on it*" (D1, Lines 28-30). Whilst explaining Bobbie's enjoyment of the intervention, his TA shared "*Well if you want to mark it out of 10, 10. He has enjoyed it*" (B, Line 45). Although each facilitator spoke positively, there were a couple of contradictions reporting some incidences of frustration. For example, Jimmy's TA commented "*I think he did find it quite frustrating at times, urm some of that is do with that it didn't do the things he wanted it to do rather than you know, he wanted to do be able to tap everything*" (A, Lines 26-28). Jimmy found it difficult to inhibit his impulses to press on anything which was of interest to him, often resulting in him making errors on the tasks.

The view that the intervention had been a positive experience was also reflected in the TAs' intention to continue to use the intervention across all the cases. Richie's TA said "*Yes, definitely. I think it's helped him quite a lot with it, so I think we will carry on using it, to support him with things in the classroom*" (D1, Lines 207-208). Millie's TA commented "*Do you know what, I will keep having another try because I think it's quite interesting to be able to use it as a little social because it is still learning for her and it will help her*" (C, Lines 259-260). Notably many suggested that they "*won't fit it in 5 days a week*" (B, Line 279). As discussed further in Section 4.9.2.2, the duration of fifteen minutes was deemed appropriate by the TA, ensuring a well-balanced curriculum was achieved and that time on the app was productive. Exposure to the intervention would therefore be reduced if not completely daily.

4.9.1.2 Theme 2: The intervention influenced the perception of the use of technology.

Significantly for this study, several of the TAs made comments about the intervention having changed the purpose of technology and introduced it as an educational tool. For many the iPad had previously been used for leisure, watching videos and as a

reward. The intervention helped them in "*recognising that we (they) can use the iPad for more than just watching YouTube or looking at stories*" (A, Lines 216-217). With the increasing use of technology, TAs commented that "*it is getting used to the fact that this is more of an educational tool I (she) think(s) is of benefit to him (Jimmy), as I (she) think(s) as he moves on that will possibly be something we (they) have to do more of*" (A, Lines 108-110). Richie's TA shared that technology:

> *"engages the children. Children nowadays use iPads and things at home, and I think it's the new technology. I think it's the way forward. I think for children with special educational needs, there is no writing involved. They can easily access it, they can listen and even if I suppose they can't listen there would be some form, they could make it that you just looked at the pictures and you just follow what the pictures do and it was very visual, I think that works really well"* (D2, Lines 71-76).

This presents further evidence of the accessibility of tablet-based learning for those with SEN, and the advantages it provides. The intervention was also said to keep "*him (Jimmy) motivated and keeping that maths work going for that little bit longer is really useful*" (A, Lines 261-262). Tablet-based learning therefore allowed maths learning too continue, using a different format than typically used in the classroom, without the tasks becoming repetitive and losing their interest.

4.9.1.3 Theme 3: Improvements in mathematical knowledge and skills

The feedback suggested that the facilitators had seen improvements in mathematical knowledge and skills. Comments indicated that pupils' number recognition and counting had improved, for example the *"quality of his accurate counting…was better" (B, Lines 154-155) and "We were working on numbers 1 to 5 but now, we are going up to numbers 1 to 10, because he seems stronger now by using the iPad*" (D1, Lines 196-198). The intervention appears to have made some of the individuals "*more confident with his (their) maths*" (D1, Line 144) and more accurate as "*he's going slower now when he's doing it where is he used to go "one two" on one thing and then keep going so you would end up having more*" (D1, Lines 165-166). However, Jimmy's TA found gains in maths "*very difficult to …. to judge*" (A, Line 150).

For two cases, there was some indication that skills were being transferred into the classroom, supporting generalisation. Bobbie's TA said she had seen improvements in the classroom; "*His counting again, it's corresponded, we do things on the smart board where he has to count the objects and again that it's not just 'I only count spots properly', it's gone back to that as well*" (B, Lines 165-167). Similarly, Richie's TA shared "*It has been nice for us to do, to see the transfer from other things we do*" (D2, Line 320).

4.9.1.4 Theme 4: Improvements in other learning skills

Facilitators reported improvements in other learning skills; including patience and confidence. Richie's TA commented "*He has absolutely loved it it's just brought his confidence out and that's really good*" (D1, Lines 232-233). Improvements in Bobbie's patience were reported:

> "*I think his patience as well. He has always been good at wanting to do his jobs but I think it's slowed him down a little and stopped him from rushing. I think he's starting to realise a purpose behind it. I think he's started to get the concept of quantity a little bit with it*." (B, Lines 167-170)

Interestingly, one of Richie's TAs shared "*I think it has helped him with his listening skills and I think it has helped him with his speaking as well*" (D2, Lines 190-191).

Two TAs also shared that they had not seen significant changes in attention or attitude to learning, saying it "*Certainly isn't any less, possibly … I wouldn't say it was any more either*" (A, Line 250) or that "*He has always been good, bless him, he has always been willing*" (B, Line 194).

4.9.2 What factors influence tablet-based learning for children with Down's Syndrome?

Three broad themes, with further subthemes, were identified in relation to research question five:

- Features of the Intervention which supported engagement
    - Visual Features
    - Language and Instructions
    - Pedagogy and Instructional Level

- Environmental factors affecting engagement
- Characteristics of the Individual

Figure 4.2 presents a thematic app addressing this question. The coded data extracts collected for each theme can be found in Appendix 8.28.

4.9.2.1 Theme 1: Features of the Intervention which supported engagement

The facilitators described a variety of features they thought had promoted the engagement of the pupils with the apps. This theme was broken down into three subthemes: the visual features of the app; the language and instructions of the virtual teacher; and the pedagogy and instructional level.

Visual features

The app is highly visual and colourful, designed to maximise the engagement of young children. Jimmy's TA commented "*it's nice, the graphics are nice and the urm you know, the colours and the way it is set out are good*" (A, Lines 56-57). Similarly, it was noted that the app is "*colourful, it's got short bursts, each activity doesn't last long so it holds his interest. It's very colourful and another side for me, is that he has had to listen to it as well*" (D2, Lines 32-33).

Language and Instructions used

Mixed perceptions were given on the individual's ability to listen and follow the instructions provided by the virtual teacher, who guides them through each step. Although references were made to the language being "*simple enough*" (B, Line 54) and because they were "*short questions*… (they) *processed it quite quickly*" (D1, Lines 178-179), individual differences existed amongst the extent to which the children listened to the instructions. Jimmy's TA reported that "*he didn't care what the voice was saying*" (A, Line 61) whereas Richie was described as having "*the volume up and he listens to it and he has been really…really careful.*" (D2, Lines 34-35).

Facilitator Role

The facilitators described their role as helping the children understand the instructions of the virtual teacher, either offering additional explanation, or repeating the auditory

instructions. Jimmy's TA said, "*there was a lot of where I was repeating instructions, rewording it, just saying oh look Jimmy we didn't hear what the lady said, let's do it again, lets listen to her again*" (A, Lines 185-186) with others "repeating an instruction or using a sign to boost the understanding of the instruction the lady had said" (B, Lines 218-219).

One suggested improvement to the app to address these concerns was:

> "*I think having some sort of sign in the corner of the screen would be a good option, if it's going to be aimed at helping special needs as well. A little bit of a help and a visual clue especially with things like in on and under, the prepositions, and the colours.*" (B, Lines 143-146)

For Bobbie and Richie, the use of sign language was frequently used by their TAs to aid understanding across their curriculum and was often used to support the language from the virtual teacher in the app. Having sign built into the app, possibly through the virtual teacher, would develop their independence when using the app.

<u>Pedagogy and instructional level</u>

The appropriateness of the material in the app and its structure allowing repetition and overlearning of key skills was also identified as a common theme. Richie's TA recognised that "*it links in with all the topics that you are doing in the classroom as well. So he has been able to use that to do the work in the classroom*" (D1, Lines 63-65). Similarly, the app's close relationship with the curriculum was commented on by Richie's other TA:

> "*I think who ever has invented this app has known part of the curriculum and I think they have done it very well. There was positional language, we have done about shapes, there was the colours, there was the sequencing, there were lots of things that we have already done.*" (D2, Lines 79-82)

Facilitators also mentioned the "*reinforced, repetitive teaching*" (A, Line 58) nature of the app, allowing students to repeat their basics skills and how it "*helped consolidate things*" (D2, Line 215).

On the other hand, a theme arose regarding the facilitators' role in choosing and guiding the topic to be practiced. The pupils were described as flicking between activities and the role of the facilitator was to "*make sure he (Richie) didn't flick too quickly between… between the different activities. That he concentrated on one at a time rather than thinking 'I'm three questions in now I'm going to go back and do something else*'" (D2, Lines 134-136). When discussing future use of the app, TAs reported that they would structure and guide topic choice more. For example, Bobbie's TA said:

> "*I would guided access it now, and I would lock it on something he needs that reinforcement for, that we are doing in class. I would lock it onto that, and we would keep doing it, we would over learn that section, until he has got the 10 questions right. So, I would do the overwrite for how long it takes, so yeah*." (B, Lines 299-302)

Further reflection upon the app's pedagogy and instructional methods included the fact that trial and error approaches could be used by a student, which the pupil could perceive as reaching success. It was reported Jimmy "*soon realised that if you tapped on everything eventually, he would get the right one*" (A, Lines 65-66). Bobbie's TA suggested that "*sometimes when you have too many goes and they guess… it would be nice if there was something where the computer knows we're not getting that we will go back a level*" (B, Lines 332-334).

4.9.2.2 Theme 2: Environmental factors affecting engagement

Environmental factors, such as time of day, location and length of time were raised as possible variables that influenced the engagement with the intervention.

To promote engagement, facilitators had intended to complete the intervention in the morning. As Richie's TA stated: "*I think probably if he has used it in the morning, he is probably, been more accepting of it because towards the end of the day he does get tired*" (D2, Lines 47-48). However, notably Bobbie "*was quite happy no matter what the time was really*" (B, Lines 70-71).

In all cases the intervention was completed in a "quiet environment" (B, Line 73), for reasons which were made clear by Richie's TA:

> "*In a quiet room. I would recommend, because with children, especially ones with educational needs they need time to process the information that the app is saying to them, but if there are other things going on around them, they might not be good at filtering that out.*" (D2, Lines 55-58)

Fifteen minutes was reported to have been a suitable duration for the three boys in the study. TAs of Jimmy, Bobbie and Richie all recognised that the boys "*would continue longer*" (B, Line 298) with the app however questioned "*what we need him to get out of it*" (B, Lines 298-299) and thought "*it can be too long and you're not using it for the right reasons*" (D2, Lines 268-269). The facilitators shared that after fifteen minutes they "*would start getting distracted*" (D1, Lines 94-95). For Millie it was thought "*15 minutes for her is probably too long*" (C, Line 265). Millie's learning tasks were all kept short and therefore her TA felt that if she does engage in the app again in the future, short periods of five minutes would be more appropriate.

4.9.2.3 Theme 3: Characteristics of the Individual

Characteristics of the individual learner were also identified as significant from the thematic analysis, including the individual's motor skills and coordination. The facilitators highlighted the difficulties the pupils had with the tracing activity on the app requiring them to follow an arrow to trace the numbers. It was "*a bit pernickety about how accurate it needed to be… it was a bit too pernickety for a child with coordination issues*" (B, Lines 119-125). The level of accuracy required was felt to be high for children with DS. There was evidence that physical support and guidance was needed for them to be successful, for example "*I would guide his hand by the wrist and help him overwrite. But he was doing the number!*" (B, Lines 210-211).

Facilitators often referred to their pupil's personality as a factor which influenced their engagement. Bobbie's TA explained that rather than it being time of day which affected his engagement "*it was more to do with something that had gone on or he's been told off because he goes in a right mood. Sit there and sulk. So, it was more that than anything, there wasn't much*" (B, Lines 68-71). Similarly, whilst discussing why Millie had not engaged successfully, her TA commented "*I think it was just, it's just her, her giving the call, that sort of thing*" (C, Line 88). This highlights the importance of placing

potentially significant interventions into a context where attention has been paid to optimising behavioural and learning strategies, attuned to positive engagement.

Finally, the pupils' previous use of technology appeared to influence their engagement. "*They are so used to [iPads] and just being able to do what they want on them*" *(A, Line 31)* was suggested as a reason for Jimmy's difficulty with listening and following the instructions. For others, their ability to use technology allowed them to be independent with the tablet. This was the case for Richie; "*when it comes to iPads and computers, he is very much aware how to use them. He doesn't need much support using things like that*" (D1, Lines 104-105).

4.9.3 Qualitative data summary

In summary, the qualitative data collected allowed exploration of the perceived outcomes of the intervention alongside an understanding of the factors which contributed to its impact. Outcomes described were positive, with evidence of improved counting ability and confidence with maths reported. Facilitators described features of the intervention which supported engagement and provided appropriate scaffolding. Children required support from their TA for additional scaffolding, task choice and guidance, and to aid understanding of the language used by the virtual teacher.

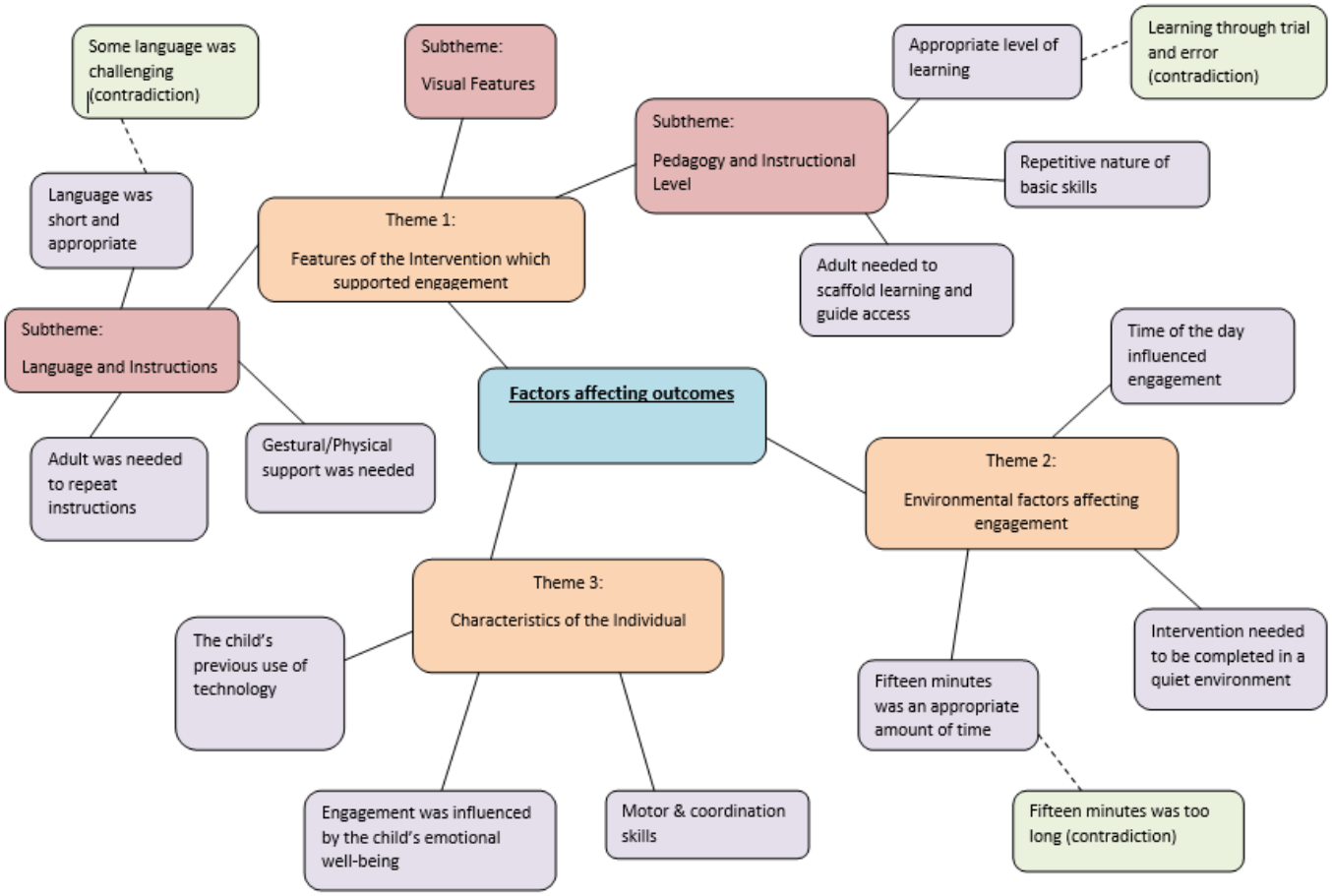


Figure 4-2: Thematic map for Research Question 5: What factors influence tablet-based learning for children with Down's Syndrome?

5 DISCUSSION

This chapter expands and explores the findings presented in Chapter 4, exploring the impact of tablet-based maths learning for young children with DS. The following research questions were explored:

1) Can onebillion's maths applications raise the maths attainment of Key Stage One children with Down's Syndrome?

2) Can the use of tablet-based applications support the engagement of children who have Down's Syndrome in their learning?

3) What is the relationship between baseline executive functioning and language skills and an individual's rate of progress?

4) What were the facilitator's perceptions of the outcomes of tablet-based learning for the children with Down's Syndrome?

5) What factors influence tablet-based learning for children with Down's Syndrome?

A case study methodology, with embedded SCEDs, resulted in a combination of qualitative and quantitative data from four individual cases exploring the impact of the onebillion maths apps. Qualitative findings are integrated with quantitative data to give greater depth and understanding to the results. Findings are summarised before being related back to the research and theoretical explanations. The research design and process are reviewed, before the inferences and conclusions from the data are presented. Finally, implications for future research, for technology provision within education for children with SEN, and for educational psychology practice will be discussed.

5.1 SUMMARY OF FINDINGS

5.1.1 Impact on maths attainment

The primary purpose of this research was to explore the effects the onebillion maths apps had on the maths learning of young children with DS (Research Question 1). This data was also triangulated with the facilitator's perceived outcomes of tablet-based

learning (Research Question 4). Data relating to these questions consisted of the repeated measures of maths attainment, pre and post measurement of maths attainment and perceived outcomes from the TA; each will be summarised below.

From the visual analysis of the repeated measures, supplemented by the effect size analysis, a positive effect of the intervention was evident for one case, Bobbie. A small increase in Bobbie's accuracy on the maths probe was evident during the intervention phase, supported by a Tau-U effect size of 0.32 which is considered a 'small' effect size, according to benchmarks by Cohen (1988). The data for Jimmy and Richie was less conclusive for the impact of the intervention on maths learning, with no evidence of an intervention effect from the visual analysis of Jimmy's data. The effect size analysis for Jimmy yielded an effect (*Tau-U*=0.17) which could be considered trivial (Cohen, 1988). However, in the context of educational research small effect sizes are common and can still be argued to indicate potentially positive outcomes (Cheung & Slavin, 2016; Kraft, 2018). Given the short intervention period (six weeks) and 15-minute sessions, a small effect for an individual learner can have practical significance. For Richie, the lack of an established baseline meant that neither visual analysis nor effect size was possible. The results reflect the individuality of the data, indicating that the impact of the intervention on maths learning may be influenced by other factors. Lack of sensitivity and difficulties with the maths probes as a repeated measure with the DS population (see Section 5.3.2.1 for further discussion), may also explain the lack of positive outcomes seen from the SCED data for Jimmy and Richie.

Given the difficulties of relying on quantitative data and on effect sizes (Kalinowski & Fidler, 2010), the practical importance of the findings also needs to be considered. Although, no confident causal inferences can be made from the data, scores from the pre and post assessment indicated an improvement in maths attainment gaining between one to three months on their maths equivalent age. Jimmy having increased the most with a three-month gain on his maths equivalent age. A one-month increase seen from Richie can be considered encouraging given research on the rate of learning in children with DS (discussed below).

Perceptions of the impact of the intervention were sought from facilitators to capture the practical significance of the intervention. The thematic analysis indicated that the

facilitators spoke positively about the intervention (Section 4.9.1.3), with evidence of improvements in basic mathematical skills being made clear for Bobbie and Richie. TAs shared that learners were taking greater care with their counting, increasing their accuracy and displaying greater understanding of the cardinality principle (explained in Section 2.1.2). For Bobbie and Richie this appeared to be transferred to the classroom in addition to whilst using the intervention.

5.1.2 Impact on engagement

The impact the intervention had on the individual's engagement with maths learning (Research Question 2) was investigated using repeated measure structured observations of their time spent on task.

As with the findings for the impact on maths attainment, the data again varies between the individuals although a more consistent pattern emerged. For two out of the three pupils for whom engagement data was collected, Jimmy (*Tau-U* effect size of 0.4) and Richie (*Tau-U* effect size of 1), demonstrated an intervention effect, showing considerably higher levels of engagement with the app in comparison to normal maths learning. In one case, Bobbie, no intervention impact was observed through the repeated measures, with an effect size which indicated a negligible change. A possible explanation for this lack of an intervention effect came from Bobbie's TA suggesting that his engagement with learning is good and therefore the data may have experienced ceiling effects. Tentative conclusions are possible, that for an individual who has low engagement with maths learning, the intervention can have a positive influence. The methodological limitations which prevent firm conclusions are discussed below.

5.1.3 Pupil level of functioning and its impact on rate of progress

Research Question 3 explored the relationships between the individual's prior level of functioning, and an individual's response to app-based learning. Given the small number of cases recruited, conclusions are significantly limited. The individual children all showed significant difficulties with their receptive and expressive language skills, as assessed by the language subtest from the NEPSY-II (Korkman et al., 2007) and the SEND Rating Scale. This is likely to have impacted their interaction with the intervention, although possibly compensated for by the adult support available.

External language scaffolding from the supporting adult, allowing the language used by the virtual teacher to be modified and repeated in an appropriate manner for the learner, may have allowed greater understanding and access to learning.

As the individuals were unable to access the inhibition subtest of executive function from the NEPSY-II (Korkman et al., 2007), for reasons including attention and lack of prerequisite skills needed, structured exploration of this factor was not possible. However, data was collected from the TAs regarding pupil functioning across a range of skills and a relationship was observed between pupil SEND Rating Scale score and their rate of progress seen from the pre and post measurements. Those who were reported to have a higher level of difficulty with learning and daily functioning had smaller improvements in their pre and post maths attainment measures. This suggests that their rate of learning is slower, or they had greater difficulty accessing the intervention.

5.1.4 Facilitators' perceptions

Qualitative data from the facilitators was also collected to further identify and explore the factors which may have affected implementation and outcomes for the individual children (Research Question 5).

5.1.4.1 Facilitators' perceptions of outcomes

Information regarding the outcomes for maths learning was triangulated with the quantitative data (Section 5.1.1). Thematic analysis identified two other areas which the TAs perceived benefited from the intervention; the use of technology for learning and other learning skills. Previous use of technology in school was commonly described as for 'leisure' purposes, including playing games and watching videos. The research had introduced the use of tablet technology for educational purposes, introducing an app which had clear learning goals (Hirsh-Pasek et al., 2015). The increasing levels of technology available in schools and potential benefits for those with SEN (Section 2.2.1) need to be communicated widely across those working in schools.

Improvement in other skills such as confidence, patience, listening and language skills were also commented on by TAs, suggesting that learners benefit from self-paced

tasks with direct instruction from the virtual teacher, and the immediate feedback they receive.

5.1.4.2 Facilitators' perceptions of influencing factors

Thematic analysis identified three themes including features of the intervention, characteristics of the individual, and environmental factors (Section 4.9.2). Features of the intervention supporting the positive engagement of the children, included its appealing visuals, the nature of instructions provided by the virtual teacher and, the appropriate content and level of the material for the child's level of learning. Facilitators appreciated the simple, clear and consistent instructions provided by the virtual teacher, carefully scaffolding progressive activities. Despite these features, the children required adult support to guide them through the intervention and scaffold language. Facilitators reported guiding the learners to appropriate topics, repeating and rewording instructions.

Given the variation in the outcomes for the individuals, discussed earlier, it is not surprising that the facilitators described varying characteristics of the individual learners which may have affected outcomes. Individual differences included their approach to learning, their previous use of technology and other skills such as motor coordination. Finally, were the environmental factors such as length of intervention sessions, time of day and the environment it was completed in.

5.2 DISCUSSION OF FINDINGS IN RELATION TO LITERATURE

5.2.1 Evaluation of the onebillion maths apps

This piece of research follows a series of evaluative studies of the onebillion maths apps in Malawi (Pitchford, 2015; Pitchford, et al., 2018) and in the UK (Outhwaite et al., 2017; Outhwaite et al., 2018; Walton, 2018). These previous evaluations, having used group designs, either quasi-experimental or RCTs, have reported positive gains for maths learning. The effect sizes reported have however, varied depending on age group and the mathematical measures used in the design. Largest effects have been seen when a curriculum knowledge (CK) measure is used, with effect size of d=3.3 in comparison to d=2.5 for the control group when low achieving EYFS II pupils, aged 4-5, used the app for the equivalent of 30 mins a day for 8 weeks (Outhwaite et al., 2017).

The CK measure, however, was researcher designed to match the content of the software. Where standardised measures of maths ability have been used smaller effect sizes have been reported with 4-5 years olds (Outhwaite et al., 2018). This reduced to no significant effect with younger pupils in EYFS I, aged 3-4 (Walton, 2018), although power being low in this study. The data collected from this case study analysis, working with a sample drawn from a population with high identified SENs, has found that positive effects of a short intervention vary at an individual level. Here, one case (Bobbie) demonstrated an effect size above what could be called 'trivial' (i.e. >0.20) (Cohen, 1988). There are number of possible explanations for the difference in findings, which are considered further below.

This piece of research was the first in the UK to explore the impact of the intervention for students with SEN. Pitchford et al. (2018) had used an observational study to investigate how children with SEND in Malawi used and benefited from the software. In both Pitchford et al. (2018) and the data found in this research, there is evidence that children with SEN can interact with tablet technology and maths apps. The learning gains however, for students with SEN requires further research. Pitchford et al. (2018) used monitoring data from the software to identify that each of their 33 students had made some learning gains, as each had passed at least one topic within the app. The extent to which this represents transferable learning skills could be questioned. Evidence indicates that measures closely aligned with the intervention show greater effects (Cheung & Slavin, 2016). The degree to which skills were generalised, being able to be used in different contexts, was not measured (Haring & Eaton, 1978). Results indicated a positive correlation between the progress rate and disability score on the SEND Rating scale (Pitchford et al., 2018) also used in this research, suggesting that those with higher levels of disability made slower progress on the software. This lends consideration to duration of the intervention.

The short intervention period of 15 minutes a day for 6 weeks in the study presented here, may provide an explanation for why consistent evidence of maths learning gains were not found. Given that all the facilitators, who successfully worked alongside their student with the intervention, reported positive gains from the app, it is possible that if the intervention period had been longer, evidence of gains may have been more

apparent. The suitability of the repeated maths measures, used in this research to detect learning gains, are discussed later in this chapter (Section 5.3.2.1).

5.2.2 Tablet-based maths learning for children with DS

5.2.2.1 Learning outcomes

The literature review (Chapter 2), outlined two studies (Agheana & Duţă, 2015; Ortega-Tudela & Gómez-Ariza, 2006) that explored the impact of technology on maths learning for children with DS, albeit not tablet-based technology specifically. Both studies suggested positive outcomes in maths learning and therefore given the variation in data found here, further research is required before wider conclusions can be made. Previous research had identified the characteristics of successful maths intervention for those with DS as direct instruction (Gersten & Carnine, 1984), modelling and guided practice (Lemons et al., 2015). These aspects have all been identified as features of the onebillion apps (Outhwaite et al., 2017), and therefore would be expected to support the learning from the intervention.

Despite no intervention effects being evident for maths attainment in SCED data excepting Bobbie's, the research did evidence the positive learning experience that children with DS could have when working on the tablet-based maths app alongside their TA. Results from the pre and post assessments using the SENT-R (Arnold et al., 2011) indicated improvements in maths ability. Although rate of progress could be explained by maturation, given that rate of progress in those with DS is not comparable to typically developing children (Wishart, 1993) this remains a positive finding.

Literature on the maths growth trajectory for children with DS is limited, however rate of learning for children with learning difficulties is not expected to be at the same rate for typically developing children (Jordon, Kaplan & Hanick, 2002). An American longitudinal study following children across their education, found evidence that students across eleven disability categories had lower maths achievement and this achievement grew slower than typically developing peers (Wei, Lenz & Blackorby, 2013). Therefore, the progress seen on the SENT-R (Arnold et al., 2011) despite being

small, provides further suggestion that the intervention provided appropriate scaffolding and can be used as an inclusive learning resource for those SEN.

5.2.2.2 Engagement

Before exploring the variables, which optimised the impact of the intervention, the positive impact the app had on engagement is discussed in relation to the literature.

The data indicated a positive impact on the participants' engagement with maths learning, although not in all cases (Section 5.1.2). Alongside this was the qualitative data from the facilitators that indicated positive experiences and impact on learning skills, such as patience. This is consistent with the wider research which indicates the benefits of using tablet technology with children with DS (Kyriakou et al., 2015) and more widely with children with SEN (Haßler et al., 2015; Clarke & Svanaes, 2014). The increase in engagement is particularly significant for children with DS due to the frequent difficulties of attention, often displaying low levels of task persistence and high levels of distractibility (Fidler, 2006; Lemons et al., 2015). Given the evidence which has indicated that attention can predict later mathematical success (Fuchs et al., 2005), methods of increasing attention and engagement with learning in children with DS has practical importance for professionals in education.

Current research indicates the difficulty in finding appropriate and engaging maths apps for children with DS (Porter, 2018). Porter (2018) have recently provided a discussion of the development of a maths app designed to develop 'discrimination of quantity' skills for children with DS. Initial results indicated that the children were benefitting more from being taught with cards rather than the iPad. From the process they identified that the children were distracted by other features of the iPad, diverting them away from the game. Porter (2018) concluded that they needed an increased level of reward and reinforcement, and a more appropriate way of scaffolding tasks in response to error rates. This further highlights the importance of finding appropriate educational apps which optimise engagement for children with DS, as seen here from the onebillion maths apps.

Research with children who have DS also suggests that their motivation for learning is likely to be influenced by earlier experiences of success and failure (Wishart, 1993,

2001). It is suggested that children with DS may develop a counterproductive learning style; highly dependent on adults, use of avoidance strategies when faced with something new and a growing reluctance to engage in learning opportunities (Wishart, 2001). Finding interventions where experiences of success are high and promote engagement with learning, such as of that seen from the onebillion app, could therefore be beneficial to future learning styles and motivation.

5.2.3 Prerequisite Skills

Research on the development of maths has identified predictors of later mathematical development including language (Purpura et al., 2011) and executive function (Cragg and Gilmore, 2013) (Section 2.11). In addition, research in Malawi has suggested that the ability to interact and learn from the onebillion maths apps was related to the child's level of functioning/disability (Pitchford et al., 2018). It was therefore important that the functioning and prerequisite skills of the children participating in this research was considered.

Although conclusions are tentative due to methodology restrictions and number of cases recruited (Section 5.1.3), the findings indicated results consistent with Pitchford et al. (2018). Those students with ratings indicating higher levels of difficulties on the SEND Rating Scale, make less progress from the onebillion maths app, in relation to their pre and post maths attainment scores. More specifically, all the cases had significant difficulties with their language, and given language is thought to predict improvements in maths (Purpura et al., 2011; Vukovic & Lesaux, 2013), may explain the low maths attainment and slow progress evident from the case studies.

Walton (2018) found that the lowest attaining students benefitted the least from the software, both in terms of their pre-existing mathematical knowledge and their receptive language skills. In exploring the data Walton (2018) suggested that for those low attaining students the app was unable to provide the appropriate support for progress within their Zone of Proximal Development (Vygotsky, 1978). In the theoretical model proposed, receptive language skills, mathematical knowledge, attention and attitude to learning were identified as individual pre-requisite skills (Walton, 2018). The children in the present research had significant SEN, and assessment of their receptive language and mathematical knowledge suggested they

were working significantly below age-expectations, and thus may provide explanation as to why maths learning gains were less. Nevertheless, it is important that the aspects of the intervention which optimise the small learning gains are considered.

5.2.4 Instruction and Scaffolding

Strengths of the software, highlighted from the thematic analysis, including its visuals, tasks modelled with clear instructions and immediate feedback, relate to existing literature on effective pedagogy and maths instruction (Section 2.1.3). The software's visual and interactive graphics, requiring learners to directly manipulate virtual objects displayed, supports active cognition and learning (Hirsh-Pasek et al., 2015). Research has shown the importance of direct, explicit instruction and modelling provided from the virtual teacher (Fuchs et al., 2008; Vygotsky, 1978). Hirsh-Pasek et al. (2015) argue that the quality of educational apps is also dependent on their ability to support engagement, which the onebillion intervention had a significant impact on for Jimmy and Richie. Engagement with educational apps is suggested to be related to the immediate feedback, providing extrinsic motivation and focusing the child's attention on the app (Hirsh-Pasek et al. 2015).

However, the use of trial and error was noted by the facilitators, with children attempting random answers until successful. This would suggest the benefit of potentially additional graded instructional scaffolding in the software, particularly when progress is limited, also proposed by Walton (2018). The difficulty of developing software which appropriately responded to an individual's errors was also noted by Porter (2018), who added a dynamic difficulty adjustment system to respond to learner's errors on their app.

The importance of repetition (Fuchs et al., 2008) in learning is well-established, and the additional repetition of basic skills which apps can provide is recognised (Hirsh & Pasek et al., 2015). Whilst repetition is embedded in the software, the ability to succeed using random trial and error may have limited the progress through the learning instructional hierarchy (Haring & Eaton, 1978). This may provide further explanation for the limited evidence of learning gains found in the data, as students may not have reached a level of maintenance and generalisation with the skills acquired. According to the instructional hierarchy, a learner will only be able to

maintain a skill if they achieved a level with allows accuracy and fluency (Haring & Eaton, 1978).

5.2.5 Role of the facilitator

Additional external scaffolding, provided by a supporting adult, can "transform children's experience from relatively haphazard poking and swiping to a guided exploration of age-appropriate content" (Hirsh & Pasek et al., 2015, p. 21). Previous evaluations of the onebillion intervention have involved learners being in groups, and therefore the level of adult support the children were receiving was likely to be less than in the study presented here. In this study, children worked on the app closely supported by their TA on an individual basis.

The facilitator role included supporting the understanding of instructions, maintaining focus on the tasks and providing cognitive scaffolding (Hammond & Gibbons, 2005) to further explain tasks. Where language was beyond the child's current understanding, adult support was important. If TAs had not sat closely alongside the students providing support, then much higher levels of disengagement and distractibility may have been presented, as seen in the low attaining students in Walton (2018). This appears to be an emerging pattern across other studies evaluating interactive technology in numeracy learning. Miller (2018) commented, from a study that evaluated the impact of numeracy based apps for children aged four or five, that "weaker students were more apt to abandon the app or use trial and error process to progress to the next level" (p.9).

Development of learning related social skills, including turn taking, cooperation and conflict resolution, in young children (aged between 3-5) has been related to the level of adult instruction in early education (Ansari & Gershoff, 2015). As children with DS often develop passive and avoidant learning styles (Wishart, 2001), adult support was likely to be needed to encourage these learning skills. Research evidence also suggests that children with DS have difficulties with early nonverbal communication skills, specifically nonverbal requesting, impacting on their ability to gain assistant from adults when needed (Mundy, Kasari, Sigman & Ruskin, 1995). Consequently, given these difficulties, it is not unexpected that children with DS may have had poor

independent learning skills, therefore requiring high levels of adult scaffolding to engage in tablet-based learning.

5.2.6 Implementation Factors

Intervention implementation in an educational setting has been shown to have an impact on intervention outcomes and therefore requires consideration here (Lendrum & Humphrey, 2012; Domitrovich et al., 2008). Evidence has shown the impact the wider context has on outcomes of the onebillion intervention for learners, including the learning environment and activities of other children (Walton, 2018). As the case studies in this research were completed across four different primary schools, various sources of potential environmental influence upon implementation existed. Generalisation across the cases is not a goal of case study research, but some extrapolations can be made (Yin, 2009). School based interventions have been noted to face many barriers (Lendrum & Humphrey, 2012). This was evident in this study through the number of sessions that the individuals experienced often adversely influenced by school variables such as TA availability or school trips. The level of adult support and scaffolding provided by the different TAs may have also varied, not directly measured, and as discussed in Section 5.2.5, research indicates there is a relationship between adult instruction and outcomes (Ansari & Gershoff, 2015).

Thematic analysis highlighted that facilitators recognised environmental influences on engagement with the intervention, including time of day, length of intervention and location (Section 4.9.2.2). Notably, In Richie's school environment finding a quiet location was difficult but was perceived as being important for his attention and focus on the app. Difficulties with attention are well documented for children and adults with DS (Fidler, 2006; Rowe et al., 2006) and therefore understanding learning conditions which optimise engagement is of importance.

5.3 Methodological Review

Despite steps taken to increase the reliability of the data gathered (Section 3.5), the reality of completing research in an applied setting such as schools, means that there are limitations which must be acknowledged (Robson & McCartan, 2016). A review

follows of the design used, the measures implemented, ethical restrictions and the issues that seem to relate to working with the DS population.

5.3.1 Review of Embedded SCED

Case studies alone have many criticisms, from the point of view of aiming to understand causal contingencies, although many of these can be overcome with the introduction of SCEDs (Barlow, et al.,2009). The A-B design, the simplest of SCEDs (Tate et al., 2016) was chosen since it was not feasible or ethical to withdraw the intervention, as would occur in designs such as the 'reversal' design (A-B-A-B) aiming to enhance internal validity. It is acknowledged that the A-B design provides the lowest internal validity and that only with major reservations can changes in the dependent variable be credited to the independent variable (Barlow et al.,2009). Kratochwill et al. (2010) provide a criterion which SCEDs must meet for causal inferences to be possible. This criterion is to be reviewed next.

Although the independent variable was systematically controlled as to when and how the intervention was introduced to each participant, there remain several limitations which are outlined below.

It has been argued that any intervention effect should be demonstrated a minimum of three times within a study for firm conclusions to be made (Kratochwill et al., 2010). With the chosen simple A-B design, this was not possible. It could be argued that the analysis of the impact of the intervention across two variables (maths attainment and engagement) for each participant and the replication of the design across multiple participants could to some extent compensate for this. However, given that visual analysis for some graphs indicated no clear evidence of an intervention effect, the internal validity is weak, and any conclusions made must remain tentative.

Kratochwill et al. (2010) also outline that any phase must include a minimum of three data points, ideally five. Due to low incidences of missing data, this minimum criterion was met in all instances apart from Jimmy's maths attainment. In this instance, only two data points were available for the baseline phase, as during this phase the probe presentation had to amended. Data from before the amendment were not included in

the analysis. This significantly reduces the inferences which can be made from this graph.

Finally, Kratochwill et al. (2010) argue that IOA should be calculated between two observers for at least 20% of data points. Unfortunately, this was not met in this study due to time and geographical constraints. It was also felt that the presence of a second observer, when collecting engagement data, influenced the performance of the individual pupils. Therefore, for ethical and reliability reasons it was decided not to complete regular joint observations. Section 4.7 displays the IOA, and despite limited joint observations, percentage agreements of 90% or above for each case does indicate an acceptable level of agreement (Yoder & Symons, 2010). A greater number of joint observations in all cases would have increased the confidence in the reliability of these measures but may have been at cost to performance which was judged to have been unethical.

5.3.2 Review of Measures

5.3.2.1 Repeated Measures

The validity of research is also dependent on the measurement tools used, and the collection of objective data in SCEDs is important to enhance validity (Mertens, 2015). There were potential threats in using data collected by TAs for the repeated observational measures of engagement. Although on-task behaviour was carefully operationally defined, observational studies are open to a level of subjectivity (Robson & McCartan, 2016). As discussed previously, calculation of IOA was an action taken to address this concern. Future research, with ethical approval, may benefit from video recording the learners interacting with the app, both to reduce the impact of observers on performance and allow greater scrutiny of the data. Analysis could then explore on-task behaviours, as well as the level and type of scaffolding provided by the TA.

Participants completed an assessment probe twice a week to establish repeated measurement of their maths attainment. The see-to-say probes were a one-minute measure of a personalised target skill, such as rational counting. The focus was on the basic concepts of number given their relationship with later mathematical development (Geary, 2011), and repeated assessments needed to be kept minimal to

reduce any distress possible to the learners. High levels of variability were evident in individual's performance, likely to be influenced by the individual's focus and motivation to complete a timed probe task. The probes may not have been sufficiently engaging and interactive, affecting their motivation to succeed, despite amendments to promote engagement such as colour. Levels of variance significantly affected the ability to establish stability in the baseline phase, reducing the validity of the data (Kratochwill et al., 2010). Without establishing consistent patterns from which forward patterns can be extrapolated, confidence in conclusions is significantly reduced. Use of repeated probe measures requires selection of a single skill for focused assessment and whilst ecologically and experimentally helpful, may restrict a broader view of individual's possible gains in other mathematical skills such as shape and size.

5.3.2.2 Standardised assessments

The use of standardised assessments with the DS population was approached with caution. It was sought as information to support the ideographic aspects of the SCED, extending it towards a case study approach. As predictors to enable insight into app responses, only tentative conclusions have been made from the data, for example language data collected from the NEPSY-II (Korkman et al., 2007). Caution was taken with the low or variable performance of children with DS on standardised assessments (Wishart, 1993). Performance can vary greatly due to their motivation, attention and instability to maintain and utilise acquired skills (Wishart, 1993). The reliability of these assessments has therefore found to be challenged and have been interpreted with caution, with awareness that performance may not reflect an individual's actual ability.

The SENT-R (Arnold et al., 2011) is a curriculum based standardised assessment used here to measure the individual's maths ability pre- and post-intervention, in order to triangulate with the SCED repeated measures. The researcher perceived that the children were more engaged with this assessment than the repeated measures of maths attainment and the standardised assessment of language used (Comprehension of Instructions, NEPSY-II, Korkman et al., 2007). This is likely to be due to task familiarity through their curriculum work, and through its visual and colourful presentation, use of concrete materials and manipulatives for the questions. Basic number skills are the focus of the SENT-R and it was used because of the importance of

such skills on later maths development (Geary, 2011). However, a measure which assesses a broader range of maths skills (such as shape and space) may have explored other skills learnt. An alternative measure used by previous research is a researcher-designed curriculum knowledge test, designed to align with the intervention (Outhwaite et al., 2017; Walton, 2018). This measure originally designed by Outhwaite et al. (2017), is a pen and paper quiz consisting of 50 questions based on the material taught in the apps. A range of topics are covered including counting, simple calculations, shape and space. However, use of a proximal measure, closely aligned with the content of the intervention, increases the risk of Type 1 errors as positive effects are seen more frequently (Cheung & Slavin, 2016).

5.3.3 Review of Qualitative data

The qualitative data collected from semi-structured interviews with the facilitators was reviewed for its quality and trustworthiness (Guba & Lincoln, 1989). Steps taken during each stage of thematic analysis to ensure credibility were outlined in Section 3.4.5.

To ensure credibility, transcripts were checked against recordings and a clear trail between the data and the interpretations made, using raw extracts are presented (Appendix 8.28). Informal member checks were undertaken, with the research informally summarising what was said to check accuracy during and after the interview. Sharing transcripts with members, would further enhance credibility however, there is some debate about the validity of member checking exercises (Thomas, 2017).

The small-scale nature of this study meant that only five interviews were completed. Transferability to different contexts could therefore be argued to be limited (Shenton, 2004).

Contradictions are noted and shared throughout the thematic analysis. However, acknowledgement is also given to the possible effects of social desirability in responding. Given the interviews were completed by the researcher, it is possible the facilitators were biased towards sharing positive perceptions and outcomes of the intervention.

5.3.4 Ethical considerations

The research was designed with full consideration of the appropriate guidelines (Section 3.6) and was granted ethical clearance by the University of Nottingham's, School of Psychology Ethics Committee (Appendix 8.18). However, during the research process, events which were not predictable arose that required further decisions. Ethical considerations were prioritised, such that they remained at the forefront throughout, despite this hindering the research and data collection in some instances.

In collaborative discussion with research supervisors and the facilitator, quantitative data collection was ended early in the process for Millie as she was showing regular refusal behaviours. Neither were pre-intervention standardised measures used due to the difficulty she had accessing them. Although data collection stopped for Millie, the setting was left with full access to the intervention for future use if her TA felt it was appropriate.

Ethical consideration also took priority when ceiling effects were identified in Richie's baseline phase. To prevent the intervention being withheld any longer, the decision was made to change the target skill on the probe after the intervention had been introduced. As a result, visual analysis was not possible for Richie's maths attainment due to the lack of an established baseline for comparison.

5.3.5 Research with the DS population

Intentions were to recruit between six and eight participants to this study, however there were difficulties in reaching that number. Working with a low incidence population meant control over recruitment numbers was limited, despite initial scoping investigations. With more available time, recruiting participants from beyond the boundary of the LA in which the study occurred could have been explored, although this may have brought more practical geographical challenges with the use of a SCED design.

The attention difficulties frequently seen in children with DS, also meant that completing standardised assessments including the SENT-R (Arnold et al., 2011) and NEPSY-II (Korkman et al., 2007) subtests was challenging. The researcher drew on her experience of working with children to make the assessments as accessible as possible;

using strategies such as sensory breaks, praise and rewards. The assessments were terminated, for ethical reasons, when the individual displayed any signs of tiredness or distress regardless of what information had been gathered.

On the other hand, working with the DS population meant that a high level of adult support was available to facilitate the research, with each case having a TA allocated to support them throughout their school day. The TAs were highly dedicated and sensitive to the child's needs. Not only did this mean they were highly supportive and engaged with the young person whilst using the app, but their dedication also aided the research process. There were very low levels of missing data, a phenomenon often experienced when conducting SCEDs in school settings. This may reflect the commitment and organised approach of the facilitators.

Despite some difficulties with the methodology and data collection, the data has important implications for the use of tablet-based learning for children with SEN, for future research and for EP practice.

5.4 Implications of Research

5.4.1 Implications for the use of tablet-based learning for children with SEN

Despite the methodological limitations described in Section 5.3, the findings indicate that the onebillion maths app may offer a useful additional maths learning resource for those with SEN in Key Stage One of schooling. Although the research did highlight that the intervention might need careful consideration as how to introduce it and optimise its use for every learner.

Building upon the findings, enhancements that may encourage further engagement from children with SEN are suggested. These include adapting the software for those with poorer motor skills, enhancing the visual prompts to support the verbal instructions, adapting the response to consecutive errors and narrowing the choice of activity to activities of an appropriate level. Each of these are discussed below.

Children with DS frequently have difficulties with fine motor skills (Spanò et al., 1999) and their ability to navigate around tablet-based technology was questioned at the start of the research. Findings suggest that they did not struggle to use and navigate

the app, possibly because of their previous experience of using technology. However, several of the tasks required a high level of accuracy of finger movement; most notably the tracing activity. Facilitators appreciated the activity, of tracing the written number, recognising it as an area of development for the young person. Although, the level of accuracy needed was felt to be too high. Frequent failures led to demotivation. It would be beneficial for the size of the number to be increased or the zone of accuracy to be widened.

Secondly, for children with DS, learning through listening is difficult and learning is optimised when using their visual strengths (Hughes, 2006). This is also the case for other developmental disorders such as Autism (e.g. Quill, 1997). Several of the facilitators felt visual support for the auditory instructions from the virtual teacher would aid understanding. Suggestions included having key written words displayed and/or incorporating some signing onto the screen. For example, have key words such as 'more than' supported by the written word and/or the virtual teacher using sign for the instruction.

Another area for development is the software's response to errors made by the learner. The repetition of the error sound was not felt to be helpful for the learner and sometimes the learner required more modelling and scaffolding. The learners could get things correct using a trial and error method, without demonstrating understanding. The software could be adapted through greater sensitivity to errors made, providing more scaffolding or returning to an earlier skill.

Finally, the facilitators often felt their role was to navigate the learner to an appropriate task and maintain focus on one skill. The learners did not follow the instruction to click on the flashing icon from the virtual teacher, thus choosing activities which may not be at an appropriate level. Therefore, it may be beneficial to narrow the choice of activities to ensure that learning within their zone of proximal development (Vygotsky, 1978) was optimised. Notably, this was also recognised as a needed improvement by Walton (2018) for younger students (3-4 years old).

5.4.2 Implications for future research

From the beginning, acknowledgement has been made of the exploratory nature of this study, and therefore only tentative conclusions can be made. The research offers cautious evidence, building upon Pitchford (2018) that tablet-based learning may support maths learning and engagement in children with DS. This study raises further questions to be addressed in the future regarding the use of the onebillion maths apps by children with SEN and more widely the use of tablet-based learning.

Firstly, the generalisability of the findings is limited by the small number of cases that were recruited to participate. Future replication of the findings would increase the confidence and reliability of the findings as the data would be argued more robust (Yin, 2009). However, generalisability of the findings, as is the case here, is often not the focus of such designs. The researcher intended to focus on the individual and was aware that generalising between individuals with such unique profiles of strengths and needs would not be beneficial. Replication of the research with learners across different settings, would allow conclusions to be firmer, as well as further exploration of patterns and themes which may emerge.

Previous research has noted the possible social benefits of tablet-based technology in the classroom, with tablet use encouraging peer interactions as learners share what is on their screens with others and provide support to each other (Miller, 2018). In the current research, the children worked on the intervention on a one-to-one basis with their TA. This meant that peer interaction and collaboration was not a factor accounted for, although given that research has suggested that collaboration is one of three key benefits from mobile learning alongside personalisation and authenticity (Kearney, Schuck, Burden & Aubusson, 2012) it is an area which could be developed in future research. Shifflet, Toledo & Mattoon (2012) found that pre-school children's social skills were enhanced as a result of the collaborative approach to learning from tablet use. This also relates to some collaborative learning support that pre-schoolers displayed whilst using the onebillion maths apps (Walton, 2018). Given the importance of social interactions on learning (Vygotsky, 1978), further research could explore the benefits that children with SEN may gain if working on the app alongside peers.

Higgins, Xiao and Katsipataki (2012) concludes that collaborative use of technology usually results in greater effect sizes than individual use.

This study explored the impact of the onebillion app with four children who had a diagnosis of DS, but more widely aimed to explore whether children with SEN would benefit in line with the results for typically developing children (e.g. Outhwaite et al., 2018). A recent review has indicated the increasing use of technology in teaching mathematics to those with moderate or severe developmental disability (Spooner, Root, Saunders & Browder, 2018) with the ability to provide explicit instruction and visual manipulatives (Bouck, Park, Levy, Cwiakala & Whorley, 2019). To expand the evidence base for the onebillion maths app, further research into for whom the intervention works, under what implementation conditions, would be beneficial (Gulliford, 2015). The benefits of technology for children with autism is documented (King et al., 2016; Knight, McKissick & Saunders, 2013) and therefore further research with this population is warranted.

Finally, further research into the maintenance and generalisation (Haring & Eaton, 1978) of the skills learnt during the use of the onebillion maths apps would be valuable. Due to time constraints this study was not able to schedule a follow-up to investigate longitudinal effects. However, previous research has found that the learning gains of the intervention groups are maintained at follow-up, although the effect size becomes smaller (Walton, 2018). In such group design, the lack of apparent maintenance was suggested to be influenced by contextual factors in the nursery such as change of class. In a single-case design, Bouck et al. (2019) also found evidence that the skills were not maintained and generalised when their app-based learning intervention was removed; performance returning to baseline level in two out of three participants with learning difficulties or Autism. An alternating-treatments ABAB design (Barlow et al., 2009) could be used in future research to explore maintenance of learning gains from the onebillion maths apps.

Evidence from facilitators suggested that some skills gained from the intervention were transferred to the classroom, which means quantitative evaluation of skill generalisation would be beneficial. Change in other skills such as language could also be explored.

5.4.3 Implications for future EP practice

A key role of the EP is to promote the use of evidence-based practice within schools and other settings (Gulliford, 2015). This research can support EPs who are involved in supporting schools with educational approaches for children with DS, or more widely for those children who may be struggling with basic mathematical skills in the early years of school. The EP can guide schools on making informative decisions and monitoring its impact in real time for the individual learner.

The results indicate that young people with SENs are likely to respond with individuality, as would be expected, and that the individual needs and profile of the child must be understood, to optimise the use of tablet-based learning. Equally, the foundation of research being developed (Chapter 2), and the data here, indicates that there are some valuable generic themes that can inform professional EP work. Empirical evidence indicates that tablet-based learning, carefully scaffolded by sensitive pedagogical support, can enable gains in maths learning, reinforcing, but not replacing, wider curriculum experiences. Tablet-based learning with the onebillion app, through the engaging and structured features of the app, supports gains in attention and engagement during the period of app-based learning. This potentially can make a positive contribution to individualised learning plans for children with SEN, whose curriculum gains are often supported by multi-faceted provision, with stepped targets.

The qualitative data collected from the facilitators gave rise to valuable information surrounding intervention implementation, again highlighting the significance of attending to the ideographic features for each context and child. The research provides further evidence of the careful planning and monitoring that any intervention in an applied setting requires.

5.5 Researcher's Reflections

Reflections are offered on the process across the last three years involving the careful design, planning, implementation and evaluation of the research. The most rewarding aspect for the researcher was introducing an inexpensive, provided for free within the research, and user-friendly intervention to schools and observing the positive experiences of the TAs and young learners. However, as with any research the process

was not without difficulty, and the researcher has reflected and learnt from the challenges that were faced in the process.

The reflections relate to the difficulty with recruitment of participants, obtaining regular measures and keeping a close track of intervention implementation in four schools, geographically spread out across a large county. The researcher was highly dependent on maintaining close communication with the facilitators, who were extremely busy and had limited time available to use email or phone communication to allow quick 'check-ins' and arrange visits.

Despite detailed planning and preparation for the research, research in schools must have a flexible and adaptable approach, recognising schools' busy schedules, other priorities, and the nature of working with vulnerable young learners.

Although the study did not achieve the desired sample size, reflections are made on the low incidences of missing data and high levels of engagement from schools. In the process, there was no attrition, a frequent issue with single case designs. This may positively reflect schools' overall desire for further support with meeting the needs of children with additional needs and intervention choice. The positive working relationship with the schools involved may also have been a contributing factor towards the high engagement observed.

A final reflection is the impact the process will have on the researcher's future career as an EP. The use of SCEDs in schools will allow continued development as a scientist-practitioner, hypothesis testing in a problem-solving framework (Birch, Frederickson & Miller, 2015). In addition to this, working in a LA which draws strongly on the use of consultation, the need to provide schools with the necessary implementation support is highlighted. Schools may identify appropriate interventions from consultation however, it is important that they are supported to consider the wider context of how and who will implement the intervention, and how to optimise for the individual learner.

6 CONCLUSION

Using a case study methodology, this research explored the use and impact of tablet-based maths learning for Key Stage One children with DS in mainstream schools. Access to the onebillion maths apps for fifteen minutes a day for six weeks was provided, and a mix of quantitative and qualitative date was collected. Across the participants a high level of variability was found in the data, although positive outcomes are indicated. Out of the four participants, three engaged well with app, enjoying daily access allowing repeated measures to be collected. In summary, data from only one participant indicated a small positive impact on maths learning. Two participants displayed improvements in their engagement with maths learning on the app in comparison to normal classroom maths learning. Methodological limitations mean that results are interpreted with caution. Overall, it appears that the onebillion maths app can be a useful supplementary form of maths learning for children with DS, however this can vary at an individual level.

Qualitative data from the facilitators of the intervention indicated positive views of the app, with perceptions of positive outcomes for each of the three participants who engaged with the software. Aspects of the apps design appreciated by them included its explicit instructions, feedback and content, consistent with previous research (Walton, 2018). It was perceived that working with the app brought wider benefits to the learners, in terms of communication, self-efficacy and attention. This study's unique contribution to the existing evidence base evaluating the onebillion maths app was exploration of its use with a SEN population in the UK. Although difficulties arose with the methodology and measures used, the data indicates that further evaluation would be beneficial given the potential for positive outcomes seen in the data.

Qualitative data also illustrated the role of the facilitating adult in scaffolding engagement and learning. Evolution and adaptation of software is also indicated by this research, in order to maximise the impact of tablet-based learning for children with SEN, and to allow close monitoring of individual progress.

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8 APPENDICES

8.1 DETAILS OF EVIDENCE BASE FOR ONEBILLION MATHS APPS

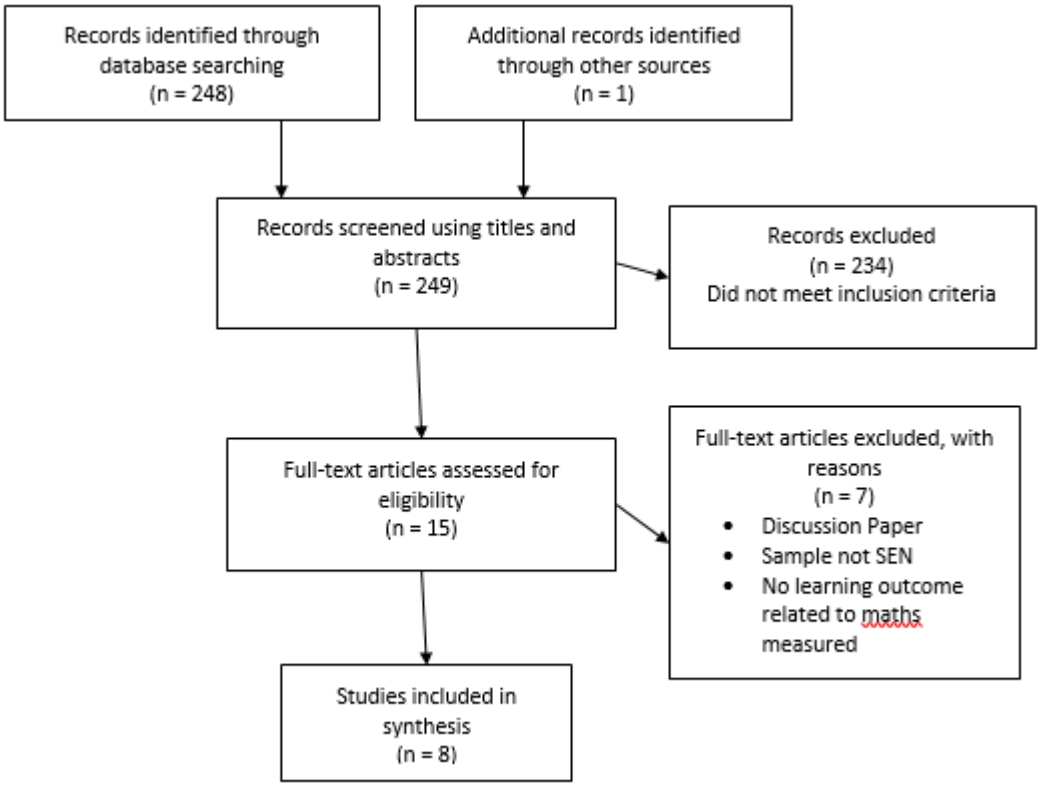
Study and Location	Design	Sample	Intervention	Measures	Outcomes
Pitchford (2015) Malawi	Randomised Control Trial Intervention group, Placebo group, Normal teaching group	282 children, standards 1-3,	8 weeks intervention 30 mins a day	Tablet based measure: - Maths curriculum knowledge (CK) - Maths Concepts (MC) Paper and Pen: - Maths curriculum knowledge generalisation (CKG)	Significant gains in MC for S2 compared to normal practice Significant gains in CK for S2 and S3 over time compared to non-maths tablet placebo and normal practice control group Significant higher performance on CKG than non-maths tablet at S2 and both (non-maths tablet and normal practice) for S3
Outhwaite, Gulliford & Pitchford (2017) UK	Quasi experimental Within subject design Pre, Post and Delayed Post	EYFS - Ages 4-5 (*n*=61) Control group KS1 *(n*=22)	6 weeks intervention 30 mins a day	Maths Curriculum Knowledge Maths Concepts (like WIAT-II) (both tablet-based assessments)	EYFS made significant learning gains with tablet. CK – *d*=1.0; MC – *d*=0.3 Immediate post-test and delayed of CK no significant difference between EYFS and KS1 (*p*=0.255) With MC no significant difference at delayed post-test (*p*=0.381)

					No effect of EAL or SES
	Quasi experimental Within subject design	EYFS (*n*=18) – Ages 4-5	13 weeks 30 mins a day	Curriculum Knowledge (paper and pen) Mathematical Reasoning (WIAT-II) Numerical Operations (WIAT-II) Non-verbal Intelligence – Block Design (WPPSI-III) Processing Speed – Symbol Search – WPPSI-III Receptive Vocabulary – WPPSI-III Memory – Number Recall and Word Recall – KABC-II	Significant learning gains CK effect size *d*=1.3 (large) MC effect size *d*=1.0 (large)
		Key Stage 1 (*n*=27) Low achieving 5-7-year olds			Significant learning gains CK effect size *d*=1.8 (large) MC effect size *d*=1.2 (large)
	Between groups design	EYFS (*n*=12) Low achievers Control group = EYFS (*n*=15) typically developing	16 weeks (50% of the time) 30 min sessions	Curriculum Knowledge (paper and pen) Mathematical Reasoning (WIAT-II) Memory – Number Recall and Word Recall – KABC-II	All groups made significant gains – but effect sizes higher for tablet group than control CK tablet – *d*=3.3; control *d*=2.5 MC tablet – *d*=2.8; control *d*=1.5

Pitchford, Kamchedzera, Hubber & Chigeda **(2018)** Malawi	Observational Study	*N*=33 Registered at SEND unit Standard 1-8	Daily session 1 hour	Teacher ratings of Pupil Disability Educator Ratings of Pupil Interaction with technology Rate of Progress (time spent on tasks passed)	SEND pupils can interact with technology. Lower disability slightly greater interaction (although not significant) All completed at least one topic SEND mean progress rate – 242 mins Mainstream progress rate – 127 mins Significant relationship between progress rate and disability score (*p*=0.033) Significant negative relationship between attention and their progress rate (*p*=0.045)
Outhwaite, Faulder, Gulliford & Pitchford **(2018)** UK	Randomised Control Trial Intervention group, time-equivalent group and control group	*N*=389 Aged 4-5	12 weeks 30 minutes daily	PTM5 (Maths Assessment Resource Service, 2015)	Significant difference between intervention and control (ES=0.31) No significant difference between intervention and time-equivalent group (ES=0.08).
Walton **(2018)** UK	Mixed methods Quasi-experimental, ability-matched design	*N*= 47 EYFS – FS1 3-4 years old	9 weeks 15mins daily	Researcher-developed measure of curriculum knowledge Standardised measure of mathematics Receptive language	Experimental group had significantly higher mathematics attainments than the control group (ES=0.38) Difference was no longer significant at 5-month follow up.

	Semi-structured Interviews			Approaches to learning	No significant intervention effect on a standardised measure of mathematics, receptive language or approaches to learning.

8.2 PRISMA DIAGRAM OF SYSTEMATIC LITERATURE SEARCH



8.3 ARTICLES EXCLUDED FROM SYSTEMATIC LITERATURE REVIEW

Search results	Reason for exclusion
Bouck, Satsangi & Flanagan (2016)	Discussion paper
Bruhn, Hirsch & Vogelgesang (2017)	Discussion paper
Cumming, Strnadova & Singh (2014)	No measure of mathematical outcomes
Maich & Hall (2016)	Discussion paper
Musti-Rao, Lynch & Plati (2015)	Discussion paper
Musti-Rao & Plati (2015)	Sample did not consist of SEN
Wang, Xie, Wang, Hao & An (2016)	Sample did not consist of SEN

8.4 CRITICAL ANALYSIS OF INCLUDED STUDIES IN SYSTEMATIC LITERATURE REVIEW

Author(s) and Year of Publication	Critical Analysis	
	Strengths of research	**Limitations of research**
Bryant et al. (2015)	Intervention details and implementation checks completed	Lack of baseline phase Only descriptive statistics provided Alternating treatment designs did not allow effects to be clearly distinguished
Calder & Campbell (2016)	Quotes from raw evidence provided Triangulation of data from students and teachers	Limited audit trail No member checks No evidence of collaborative work on analysis/themes
Chmiliar (2017)	Triangulation of data from students, parents and teachers.	No audit trail, external auditors or member checks
Fernandez-Lopez et al. (2013)	Intervention details clear Instrument reliability reported	No control group Pre and post assessment Only percentage increase reported – no raw data or children's starting skills and abilities.
Kaur, Koval & Chaney (2017)	Collaborative work between researchers to identify themes. Comparing and clarifying until agreement reached. Direct quotes for evidence.	Limited audit trail of how data was collected, transcribed etc… No evidence of member checks
Ok & Bryant (2016)	Intervention details provided Clearly operationalised DV Multiple baseline, minimum of 3 data points met in each phase Implementation and Inter scorer agreement completed Maintenance assessment	Intervention phase limited to 3 weeks App in cooperated into an individual teaching session, can't decipher precise impact of apps.
Pitchford et al. (2018)	Intervention details provided Statistical Analysis clear	Correlational study therefore causality not inferred.
Zhang et al. (2015)	Details of three apps provided	No control group Small sample of 18 students Pre and Post assessments. Practice effects possible – the same assessment used for pre and post assessments Procedure unclear

8.5 Expression of Interest Letter



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e: psychology@nottingham.ac.uk

www.nottingham.ac.uk/psychology

A study to investigate the impact of Maths Apps on the Numeracy Attainments of Key Stage One pupils with Down's Syndrome.

Dear Headteacher and SENCO,

I am a Trainee Educational Psychologist studying at the University of Nottingham on placement with XXXXX Educational Psychology Service. As part of my course I am undertaking research investigating the impact of a tablet-based Maths App on the numeracy attainment of children with Down's Syndrome in Key Stage One. I am therefore seeking primary schools within the local area who may be interested in participating.

The aim of the research is to evaluate the effectiveness for children with Down's Syndrome of a series of maths applications produced by the organisation onebillion. Onebillion is a not-for-profit company who have developed the apps with the aim of improving children's numeracy in the early years of school. The apps (Maths age 3-5, Maths age 4-6) are a series of carefully structured apps designed in line with the National Curriculum requirements and have proven efficacy. They are designed to be colourful and engaging activities, child-paced, providing progressive content with immediate feedback for the learner.

My aim is to work alongside mainstream school staff to identify children in Key Stage One (academic year 2018/19) who have a diagnosis of Down's Syndrome who may benefit from such an intervention. To participate the school must have access to an iPad for the app to be used on. The software will be provided.

This will involve allowing the child to have access to the tablet-based maths application programme on a regular basis for a sustained period. Children's progress will be measured and evaluated.

The process would involve:

- An initial meeting with the appropriate school staff and parent(s)/carer(s) to provide more detail on the project, allow any questions you may hold to be discussed, and to discuss the individual's needs and suitability for the intervention.
- An initial assessment of the individual's mathematical attainment as well as their executive functioning and language. This will be completed on a one to one basis, between myself and the child in the school setting. Consent from the children will be sought.
- For the intervention phase, the young person will require access to the maths application whilst working with a teaching assistant for 15 minutes a day.
- A teaching assistant, working alongside the child, to take regular measures of mathematical attainment and engagement with tasks. This will need to be completed for 3 weeks prior to the intervention being implemented, and then continuing for a period of 6 weeks during the intervention phase. These measures will need to be completed twice a week but should last no longer than 10 minutes. Full training will be provided by the researcher.
- Regular contact and visits will be made between the school and the researcher.
- At the end of the intervention phase, the researcher will complete a final assessment of the individual's mathematical attainment.
- An interview between the researcher and the teaching assistant who works alongside the selected child will be completed as the research comes to a close.

All the work will be carried out professionally in line with the ethical guidelines of the British Psychological Society, which includes ensuring the confidentiality of data and the right to withdraw from the study at any time. Parents/Carers will be fully informed about the nature of the research and will be invited to give consent for their child to participate. The children involved will also be provided with information and their consent will be gained. On completion of the research, I will provide written feedback summarising the study and its findings and I can provide additional feedback in person as well if wanted.

I would be grateful from hearing from you if you think your school may be in a situation to help with my research and have a pupil who may be suitable for such intervention. My contact details, along with my supervisors, are provided below. We can arrange to meet and discuss any questions if you wish at this stage.

Thank you for your time.

Contact Details:

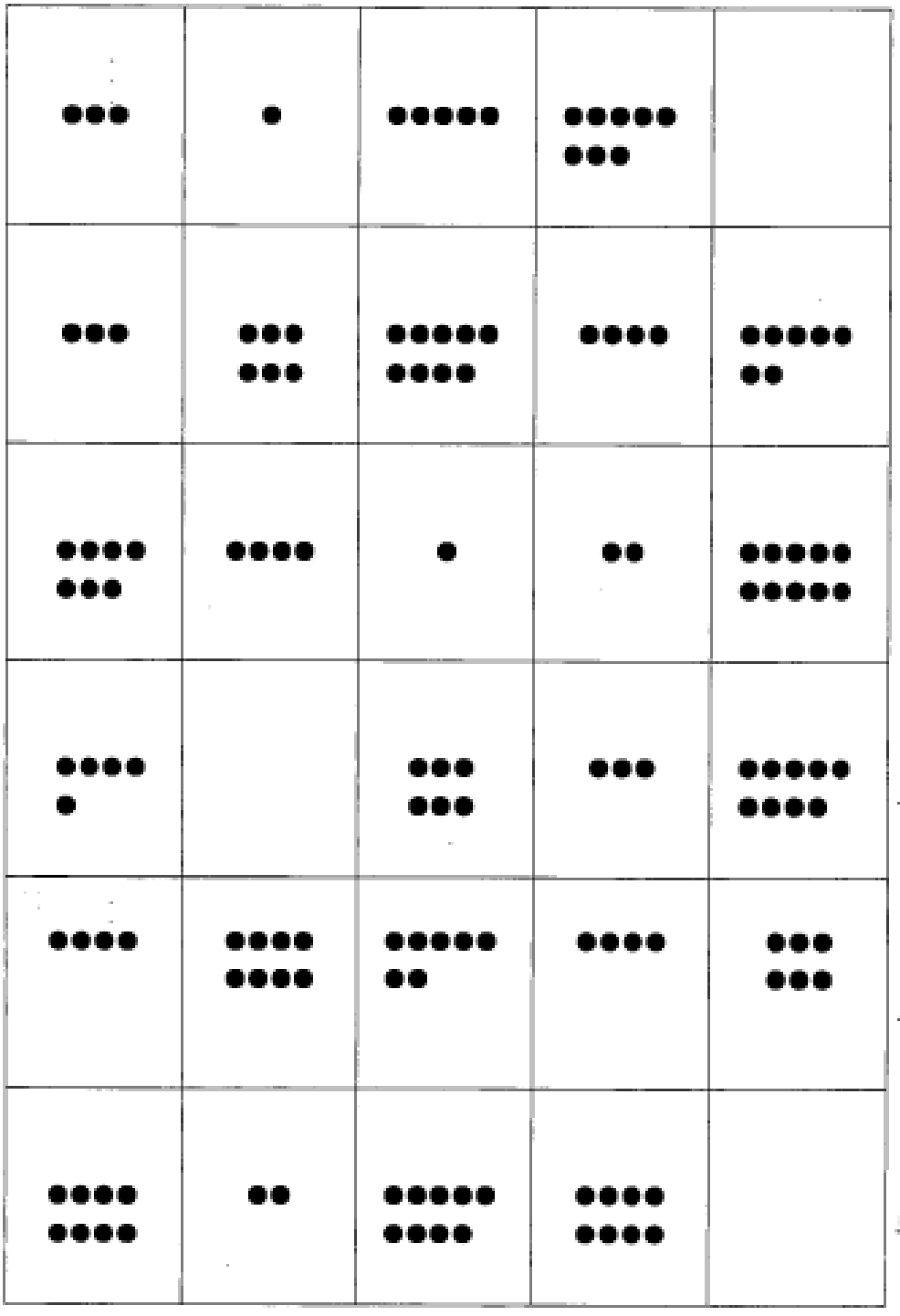
Kate Allison (Trainee Educational Psychologist and Researcher) at: lpxka@nottingham.ac.uk
*Anthea Gulliford (Researcher Supervisor) at:*anthea.gulliford@nottingham.ac.uk

Kind Regards,
Kate Allison
(Researcher and Trainee Educational Psychologist)

8.6 EXAMPLE PROBE

Probe: C3 – Rational counting (one group)

Aim rate: 15 c.p.m. Date:



Birmingham City Council
Children, Young People & Families
Educational Psychology Service

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8.7 STRUCTURED OBSERVATION

Time Interval (every 60 secs over a 10 min sample)	On/off Task	Comments
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

8.8 ADAPTED WASHINGTON QUESTIONNAIRE

Questionnaire

Amended from: **The Washington Group Short Set of Questions on Disability**
These questions ask about difficulties the named child may have.

1. Does s/he have difficulty seeing, even if wearing glasses?
a. No - no difficulty
b. Yes – some difficulty
c. Yes – a lot of difficulty
d. Cannot do at all

2. Does s/he have difficulty hearing, even if using a hearing aid?
a. No- no difficulty
b. Yes – some difficulty
c. Yes – a lot of difficulty
d. Cannot do at all

3. Does s/he have difficulty walking or climbing steps?
a. No- no difficulty
b. Yes – some difficulty
c. Yes – a lot of difficulty
d. Cannot do at all

4. Does s/he have difficulty remembering or concentrating?
a. No – no difficulty
b. Yes – some difficulty
c. Yes – a lot of difficulty
d. Cannot do at all

5. Does s/he have difficulty (with self-care such as) washing all over or dressing?
a. No – no difficulty
b. Yes – some difficulty
c. Yes – a lot of difficulty
d. Cannot do at all

6. Using their usual (customary) language, does s/he have difficulty communicating, for example understanding or being understood?
a. No – no difficulty
b. Yes – some difficulty
c. Yes – a lot of difficulty
d. Cannot do at all

8.9 SEND RATING SCALE

RECORD SHEET

Special Educational Needs and Disability (SEND) Ratings

Child's Name:
Date of Birth:
Date of Questionnaire Completion:

Indicate the relationship between the person giving the ratings for the child/adult by checking the appropriate box:

Parent/Caregiver	
Teacher	
Teaching Assistant	
Doctor/Nurse	
Self-report	
Researcher	

Indicate the level of difficulty for each of the following areas of functioning for the child/adult:

Category	No Difficulty	Mild Difficulty	Moderate Difficulty	Severe Difficulty
Vision				
Hearing				
Mobility – upper torso (head, hands and arms)				
Mobility – lower torso (back, legs and feet)				
Language – expressive/speech				
Language – Receptive/comprehension				
Learning				
Memory				
Attention/concentration				
Social Interactions				
Emotional control/sensitivity				
Mental Health – depression, anxiety, post-traumatic stress				

Indicate if the child/adult has received any of the following diagnoses:

Diagnosis	Yes	No
Down's Syndrome		
Autism		
Hyperactivity		
Spina Bifida		
Cerebral Palsy		
Hydrocephalus		
Asthma		
Epilepsy		
Preterm Birth (before 31 weeks gestation)		
Albinisim		
HIV		
Amuptation		

Comment on any specific difficulties not covered above:

8.10 Initial Contact Meeting Notes

Initial Meeting

Present: Researcher, SENCo, Parent

Explain purpose of research

Explain role of researcher as a Trainee Educational Psychologist completing research as part of doctorate with University of Nottingham.

Evaluating the impact of intervention for children with Down's Syndrome

Previous Research using the intervention – Impact has previously been evaluated as a universal classroom intervention with children with FS1, FS2, and Year 1. Researchers have yet to evaluate its impact for pupils with special educational needs in the UK.

Intervention Details

The onebillion tablet intervention involves two separate apps, *Maths Age 3-5* and *Maths Age 4-6.* Both of these apps follow topics in the National Curriculum for Foundation Stage. A 'virtual' teacher delivers the 'lessons', providing clear modelling and instructions for each topic area, followed by opportunities for independent practice.

A full list of the topics on the apps and a breakdown of the activities is available on the onebillion website.
https://onebillion.org/apps/maths3to5
https://onebillion.org/apps/maths4to6

Within each topic area there are ten different activities for the children to complete to practice the skill, followed by a short quiz. Each child has their own profile on the app so that they can progress through the activities at their own pace and learning is personalised for them. Once children have completed the quiz and answered each question correctly they receive a virtual certificate.

Participant Suitability

Inclusion Criteria:

1. The pupil has a diagnosis of DS.
2. The pupil is in Key Stage One in a mainstream primary school.
3. The pupil is not displaying behaviours which may make them unsuitable for accessing the intervention.
4. The pupil is not receiving any targeted Numeracy intervention already.
5. The pupil does not have other significant difficulties which may hinder their access to the app.

Process Details

- An initial assessment of your child's mathematical attainment as well as of an aspect of their executive functioning and language. This will be completed on a one to one basis, between myself and the child in the school setting. Consent from the children will be sought.
- A teaching assistant, working alongside your child, to make regular measures of their mathematical attainment and their engagement with tasks. This will need to be completed for 3 weeks prior to the intervention being implemented, and then continuing for a period of 6 weeks whilst the intervention is being implemented. These measures will need to be completed twice a week but should last no longer than a few minutes two times per week for your child.
- For the intervention phase, your child will work on the tablet-based maths application for 15 minutes a day alongside their teaching assistant.
- Regular contact and visits will be made between the school and the researcher.
- At the end of the intervention phase, the researcher will complete a final assessment of your child's mathematical attainment.

Next Steps

Paper copy of parental information and consent sheet shared today. Parents can take these away and return to school within the following week providing consent for involvement.

If parental consent is received:

- Further consent will be gained from SENCo and Headteacher
- Facilitator training – gaining consent from supporting adult
- Baseline measurement will commence by supporting adult
- Initial assessment by researcher. Child's consent gain at the beginning of this session.
- Intervention to begin after three week of baseline measurements

Information Needed from Parents if consent is gained:

Date of Birth

Medical Diagnoses

Child's use and experience of tablet-based technology at home.

8.11 Information and Consent Letter for Schools

A study to investigate the impact of Maths Apps on the Numeracy Attainment of Key Stage One pupils with Down's Syndrome.

Ethics Approval: S1083

Researcher(s): Kate Allison *Email:* lpxka@nottingham.ac.uk

Supervisor(s): Anthea Gulliford *Email:* anthea.gulliford@nottingham.ac.uk

Outlined below are the responsibilities of the school and the researcher the with regards to this research, and the potential benefits for the school of taking part in the research. This information is supplementary to that which can be found in the 'Expression of Interest Letter'. Please read the information carefully before completing the attached consent form.

Responsibilities of the researcher:

- Assess the participants baseline mathematical attainment, executive functioning and language level pre-intervention.
- Re-assess the participants mathematical attainment after 6 weeks of using the application.
- To train the staff member in the use of the tablet based maths application
- To train staff in the use of the observational technique to be used to collect data
- To keep in regular contact with the school to offer ongoing support and advice over the course of the research
- To analyse the data collected and feedback the research outcomes to all involved

Responsibilities of school staff:

- To implement the maths application intervention with the frequency specified at each phase of the research (completed for 15 minutes daily during the intervention phase).
- To undertake regular time-sample observations of the participants for data collection (10-minute observation twice weekly).
- To undertake regular assessment of the participants mathematical attainment using provided material (1-minute probe twice weekly).

- Throughout the course of the research, to monitor the assent and wellbeing of the participant, and to contact the researcher should concerns arise.
- The teaching assistant working alongside the participant to be available to be interviewed upon completion of the intervention phase. This interview to last no longer than 1 hour.

Potential benefits to the school for taking part:

- The opportunity to take part in a piece of research which aims to inform the evidence base for the effectiveness of a numeracy interventions for those with special educational needs
- The school will be given full access to the software upon completion of the research and the staff member(s) involved will be equipped with the knowledge and skills to be able to implement an evidence-based intervention, which can be applied to other pupils in the school if wished.
- The opportunity to gain detailed monitoring data about the impact of the intervention which can inform future planning for this pupil, and potentially others.

Headteacher and SENCO Consent Form

A study to investigate the impact of Maths Apps on the Numeracy Attainment of Key Stage One pupils with Down's Syndrome.

Ethics Approval: S1083

Researcher(s): Kate Allison *Email:* lpxka@nottingham.ac.uk
Supervisor(s): Anthea Gulliford *Email:* anthea.gulliford@nottingham.ac.uk

Please read and answer the questions below:

- Have you read and understood the Information Sheet? YES/NO
- Have you had the opportunity to ask questions about the study? YES/NO
- Have all your questions been answered satisfactorily (if applicable)? YES/NO
- Do you understand that you are free to withdraw from the study? YES/NO (at any time and without giving a reason)
    - I give permission for the data from this study to be shared with YES/NO

  other researchers provided that mine and the school's anonymity is completely protected.
- Do you agree to take part in the study? YES/NO

"This study has been explained to me to my satisfaction, and I agree to take part. I understand that I am free to withdraw at any time."

Name of School:

Signature of Headteacher: Date:

Name (in block capitals):

Signature of SENCO: Date:

Name (in block capitals):

I have explained the study to the above participant, and he/she has agreed to take part.

Signature of researcher: Date:

Name (in block capitals):

8.12 Information and Consent Letter for Parents



University of Nottingham
UK | CHINA | MALAYSIA

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School of Psychology

The University of Nottingham
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A study to investigate the impact of Maths Apps on the Numeracy Attainment of Key Stage One pupils with Down's Syndrome.

Ethics Approval Number: S1083

Researcher: Kate Allison

Supervisor: Anthea Gulliford

Contact Details:

Kate Allison (Trainee Educational Psychologist and Researcher) at:
lpxka@nottingham.ac.uk
*Anthea Gulliford (Researcher Supervisor) at:*anthea.gulliford@nottingham.ac.uk

Dear Parent/Guardian

I am a Trainee Educational Psychologist studying at the University of Nottingham on placement with XXXXX Educational Psychology Service. As part of my course I am undertaking research investigating the impact of a tablet-based maths application on the numeracy attainment of children with Down's Syndrome in Key Stage One. I am writing to inform you about my research and to invite your child to take part in the study. The school have identified your child as a possible participant, please be assured that no personal details have been shared.

The aim of the research is to evaluate the effectiveness of a series of maths applications produced by onebillion. Onebillion is a not-for-profit company who have developed a series of apps with the aim of improving children's reading and numeracy in the early years of school. The numeracy apps (Maths age 3-5 & Maths age 4-6) are a series of carefully structured apps designed in line with the National Curriculum requirements. There is evidence that the applications help support children's progress

in Maths, when used alongside the normal classroom maths curriculum. The apps are designed to be colourful and engaging activities, providing carefully structured content with immediate feedback for the learner. My research aims to explore the impact of the apps for children with Down's Syndrome.

The process would involve:

- An initial meeting with the appropriate school staff and yourself to provide more detail on the project, allow any questions you may hold to be discussed, and to discuss your child's needs and suitability for the intervention. If you decide to give your consent, then I would like to ask you some questions about your child at this point.
- An initial assessment of your child's mathematical attainment as well as of an aspect of their executive functioning and language. This will be completed on a one to one basis, between myself and the child in the school setting. Consent from the children will be sought.
- A teaching assistant, working alongside your child, to make regular measures of their mathematical attainment and their engagement with tasks. This will need to be completed for 3 weeks prior to the intervention being implemented, and then continuing for a period of 6 weeks whilst the intervention is being implemented. These measures will need to be completed twice a week but should last no longer than a few minutes two times per week for your child.
- For the intervention phase, your child will work on the tablet-based maths application for 15 minutes a day alongside their teaching assistant.
- Regular contact and visits will be made between the school and the researcher.
- At the end of the intervention phase, the researcher will complete a final assessment of your child's mathematical attainment.

The whole procedure should last 9 weeks.

All the work will be carried out professionally and in line with the ethical guidelines of the British Psychological Society, which includes ensuring the confidentiality of data. Your child will not be identifiable through any research digests. You have the right to withdraw from the study at any time. I will seek to inform your child and gain their consent in a way that is appropriate to them. On completion of the research, I will provide written feedback summarising the study and its finding. I can provide additional feedback in person as well if wanted.

I hope this letter has been useful in providing you with an initial idea of what the research would entail. Please contact me if you wish to meet or speak in person to further discuss this research.

If you are happy for your child to participate, could you please complete the enclosed consent form and return it to your child's school or bring it with you to our initial meeting. Although you are now aware of the intervention, please continue as normal at home until the research is complete.

If you have any questions or concerns, please don't hesitate to ask. We can also be contacted after participation at the above address.

If you have any complaints about the study, please contact:
Stephen Jackson (Chair of Ethics Committee)
stephen.jackson@nottingham.ac.uk

Thank you for your time.

Yours sincerely,

Kate Allison
(Trainee Educational Psychologist)

Parental Consent Form

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

A study to investigate the impact of Maths Apps on the Numeracy Attainment of Key Stage One pupils with Down's Syndrome.

Ethics Approval Number: S1083

Researcher: Kate Allison Email: lpxka@nottingham.ac.uk

Supervisors: Anthea Gulliford Email: anthea.gulliford@nottingham.ac.uk

Please answer the following questions:

- Have you read and understood the Information Sheet? YES/NO
- Have you had the opportunity to ask questions about the study? YES/NO
- Have all your questions been answered satisfactorily? YES/NO
- Do you understand that you are free to withdraw your child from the study? (at any time and without giving a reason) YES/NO
- I give permission for my child's data from this study to be shared with other researchers provided that anonymity is completely protected. YES/NO
- I give permission for my child's data/numeracy assessment to be shared with their school. YES/NO
- Do you agree for your child to take part in the study? YES/NO

"This study has been explained to me to my satisfaction, and I agree for my child to take part. I understand that I am free to withdraw my child at any time."

Signature of the Parent/Carer: Date:

Name (in block capitals)

I have explained the study to the above participant, and he/she has agreed to take part.

Signature of researcher: Date:

8.13 SUPPORTING ADULT CONSENT

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Consent Form for Supporting Adult

A study to investigate the impact of Maths Apps on the Numeracy Attainment of Key Stage One pupils with Down's Syndrome.

Researcher's name: Kate Allison
Supervisor's name: Anthea Gulliford

As you are aware the school and parents of the pupil whom you support have agreed to take part in my research, investigating the impact of Maths Apps on the Numeracy Attainment of Key Stage One pupils with Down's Syndrome. This will involve you supporting the child to access the onebillion maths applications on a tablet device for 15 minutes a day in addition to their normal numeracy teaching. Thank you for your engagement in this study.

Following full training from the researcher, you will measure the child's mathematical attainment and engagement twice a week for the during of the research (9 weeks) you are also asked to complete brief daily session logs regarding the child's engagement with the intervention.

Before the intervention commences, I would like to ask you to complete two questionnaires about the child's current level of functioning.

Following the completion of the research, I would like to interview you, to gather your perspective on the intervention including its impact, its implementation and suitability for the child you support. This interview will be recorded by the researcher and deleted once transcribed. All data will be kept strictly anonymous. You can ask me any other questions you have about the research at any time. You have the right to withdraw at any point in the process.

Please read the following statements carefully:

- I have been informed of and understand the purposes of the research
- I have been given an opportunity to ask questions and to speak to or meet with the researcher.
- I understand that any information and data gained during the study will be kept anonymous and confidential.
- I understand that I may contact the researcher or supervisor if I require further information about the research.
- I consent to being interviewed as part of the research.

Name of child: …….

Name of supporting adult: ……

Signature: ……

Date: …….

Contact details:
Researcher: lpxka@nottingham.ac.uk
Supervisor: anthea.gulliford@nottingham.ac.uk

8.14 Facilitator Training Sheet
Facilitator Training

What is the onebillion mathematics tablet intervention?
The onebillion tablet intervention involves two separate apps, *Maths Age 3-5* and *Maths Age 4-6.* Both of these apps follow topics in the National Curriculum for Foundation Stage. A 'virtual' teacher delivers the 'lessons', providing clear modelling and instructions for each topic area, followed by opportunities for independent practice.

A full list of the topics on the apps and a breakdown of the activities is available on the onebillion website.

https://onebillion.org/apps/maths3to5

https://onebillion.org/apps/maths4to6

Within each topic area there are ten different activities for the children to complete to practice the skill, followed by a short quiz. Each child has their own profile on the app so that they can progress through the activities at their own pace and learning is personalised for them. Once children have completed the quiz and answered each question correctly they receive a virtual certificate.

The first three weeks…

- Normal school routines to be continued for the first three weeks, before any intervention is introduced.
- During these three weeks, you will take assessment measures twice a week. This included both a maths probe and completion of the on/off task observation. Further details of these two assessments can be found below.

How will the intervention run?

- The intervention will then run for 6 weeks, for 15 minutes a day. This should be at a similar time each day and be in addition to normal maths teaching.
- Continue to complete assessment measures twice a week as done previously.
- Complete a session log daily when the intervention is being delivered.
- The app does not replace the need for some teaching support, although this will depend on the needs of each individual child. Children should be supported to work independently where possible but provide additional teaching support so that they can make progress when required.

Support varies depending upon the child's need but might include:
- Providing praise, encouragement and prompts to maintain attention
- Prompting the child to press the ear in the top right corner to listen again to the instructions

- Providing additional teaching support where needed

Important points to note

- **Quizzes:** If children don't pass a quiz, then consider asking them to go back and practice some of the earlier activities before trying again. However, after a few turns, provide them with support to complete the quiz if necessary so that they don't become discouraged. They can then move onto the next topic area, which may be a different area of maths that they can succeed at.
- **Monitoring progress**: Take care to monitor children's progress carefully, provide extra support and try a different teaching approach instead if necessary so that children don't become frustrated or discouraged. If any child experiences persistent distress, despite additional teaching support, they should be removed from the iPad.

Maths Probe – to be completed twice a week

These will be designed by the researcher in collaboration with yourself to ensure they are at an appropriate level to the individual.
Four probes will be provided, each testing the same skill, that can be presented in a randomized order. The researcher will provide full details.
Probes are designed to allow a short and simple assessment of a child's performance. A child has one minute (60 secs) to complete as many as they can without adult support.
The number of correct and incorrect responses must be recorded.

On/off task observation – to be completed twice a week

During the first three weeks this will needed to be completed whilst the child is engaged in normal maths teaching. Once the intervention has started this will be whilst they are engaged with the apps.
Following the schedule provided, for a duration of ten minutes please record whether the child is on/off task every 60 seconds. Any additional comments are welcome.
A child is considered to be on task if they are:

- Looking at the iPad screen
- Using the app software
- Receiving facilitator support

Daily Session Logs

Please complete a daily session log, provided by the researcher, after completing the 15-minute session on the apps.

If you have any questions regarding the research or experience any difficulty, please get in contact on lpxka@nottingham.ac.uk

Thank you for your support and involvement in my research.

Kate Allison

(Researcher and Trainee Educational Psychologist)

8.15 Child Consent Form

Hi (insert child's name), my name is Kate.

I would like to work with you and your teachers to see if we can help your Numeracy with a special game.

You would play this special maths game every day with (insert Teaching Assistants name) on a tablet.

Your teaching assistant and I will ask you some maths questions to look at what you have learnt.

You can stop at any time.







Please answer the questions here by choosing YES/NO or colouring your answer.

Key: Colour  if you want to answer **YES**

Colour  if you want to answer **NO**

Do you understand? **YES** **NO**



I am happy to take part in the project. **YES** **NO**



8.16 TIMELINE

	Nov 17	Dec 17	Jan 18	Feb 18	Mar 18	Apr 18	May 18	Jun 18	Jul 18	Aug 18	Sep 18	Oct 18	Nov 18	Dec 18	Jan 18	Feb 18	Mar 18	Apr 18	May 18
Finalise Proposal and Design																			
Submit Ethics Proposal																			
Identify Setting and Engage with Stakeholders																			
Literature Review																			
Gain consent from Parents																			
Design with school																			
Data collection																			
Write Methodology																			
Data Analysis																			
Feedback to schools/parents																			
Write Results and Discussion																			

8.17 Interview Schedule

Semi-Structured Interview for TAs

Thank you for agreeing to be interviewed as part of the research. Please be honest and take your time to think of your response, there are no right or wrong answers. Your responses will be kept confidential and remain anonymous. This interview will be recorded but please be assured it will be deleted after I have made my notes.

Topic	**Questions**	**Prompts**
Background Information	Can you confirm your role at the school and how long you have worked with XXX for? How much of the week do you support XXX? Did you use the iPad regularly with XXX prior to this research, and if so what for?	
Intervention implementation	What did you notice about how X engaged with the app? How much do you think XXX enjoyed learning maths on the app software with you? What were the factors that helped this? What were the factors that hindered this? What were the strengths of the app in your view? What were the hurdles for you in using the app with X, if any?	Energy? Time of day? Location? Length of time – did this correlate with apparent enjoyment? Were any motivational techniques used?

Impact	Are there any changes to the software you would recommend supporting the access and learning for children with SEND? How far do you think the app helped X's development? • Language • Maths • Independence • Attitude • Attention Are there any other areas that you feel the app has helped X to develop in?	Did X's vocab grow at all? Did you see any improvements in his maths? did they ask for the tablet? Fetch it? Load the app?
Support	Whilst you were working with XXX on the app, what did you find yourselves doing to assist? Technological support Pedagogical support Language support Attention support Behavioural support	Did XXX need help navigating around the iPad and the app software? What sort of language support was required? Do you feel like additional teaching support was required? If prompts were used were they: • Verbal • Gestural • Physical Or combination of these?
Child and predictors	What was XXX's maths like before the research started?	Would you say literacy or numeracy was stronger?

	What factors do you think influence XXX's maths learning? Which features of the app do you think support XX learning of maths?	Language, motor skills, attention
<u>Future</u>	Do you think you will continue to use the onebillion maths software with XXX? If you intend to continue using the onebillion maths app with XX, are there any changes to how you have used it so far that you would like to make? Can you see other children in the school using the app in the future?	Will you make any changes to its use? Timing, duration, more/less often during the week Who do see it benefitting the most?
Any other comments?		

Thank you for your time today and your efforts with intervention implementation. The recording will now be transcribed before further analysis. Please remember that all the data will be kept anonymous and you have the right to withdraw your data if you wish.

Once again, thank you for your support.

8.18 ETHICS APPROVAL LETTER

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

School of Psychology
The University of Nottingham
University Park
Nottingham
NG7 2RD

tel +44 (0)115 846 7401 or (0)115 951 4044

SJ/tp

Ref: S1083

Thursday 24th May

Dear Kate and Anthea,

Ethics Committee Review

Thank you for submitting an account of your proposed research **"A study to investigate the impact of Maths Apps on the Numeracy Attainments of Key Stage One pupils with Down's Syndrome"**

That proposal has now been reviewed and we are pleased to tell you it has met with the Committee's approval.

However:
Please note the following comments from our reviewers;

Reviewer One:
- Accepted

Reviewer Two:

- The researcher states that the teaching assistant as the right to withdraw at any time. She should clarify whether this refers to the right to withdraw their interview data and consider whether this is possible after transcription has taken place. If it is no longer possible to identify participants to withdraw their data after transcription has taken place, the researcher should give participants a timeline (or date up until) when they can request this.
- Information sheet for Parents or Carers should state how the researcher identified the child with the school and reassure parents that the researcher does not have their contact information at this point. The school is acting as the gatekeeper until a parent consents.
- The inclusion criteria outlines "The pupil is not displaying behaviours which may make them unsuitable for accessing the intervention". This seems vague to me, therefore I would suggest the researcher make it clearer with some examples and put it on the headteacher information sheet.

Final responsibility for ethical conduct of your research rests with you or your supervisor. The Codes of Practice setting out these responsibilities have been published by the British Psychological Society and the University Research Ethics Committee. If you have any concerns whatever during the conduct of your research then you should consult those Codes of Practice. The Committee should be informed immediately should any participant complaints or adverse events arise during the study.

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Independently of the Ethics Committee procedures, supervisors also have responsibilities for the risk assessment of projects as detailed in the safety pages of the University web site. Ethics Committee approval does not alter, replace, or remove those responsibilities, nor does it certify that they have been met.

Yours sincerely



Professor Stephen Jackson
Chair, Ethics Committee

8.19 Debrief Letter

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24.01.19

Dear Parents and School of XXXX,

Thank you for allowing XXXX to take part in the research study on the impact of the Maths Application on the numeracy attainments of children who have Down's Syndrome, which has now come to an end for XXXX. I have attached a summary document of the assessment data that was collected during the research process. Please note that these scores were the result of a one-off assessment and should always be interpreted alongside other information in the wider context. If you wish for further review or analysis, please contact school staff for further discussion, who may advise you or seek further consultation.

Further analysis of all the data collected will continue in the future months. If you would like any additional information in the future or would like to discuss any of the information shared, please do not hesitate to contact myself by email at kate.allison@nottingham.ac.uk.

Participation in the study is totally voluntary and you are still free to withdraw the data. All data collected will be kept anonymous and used for research purposes only.

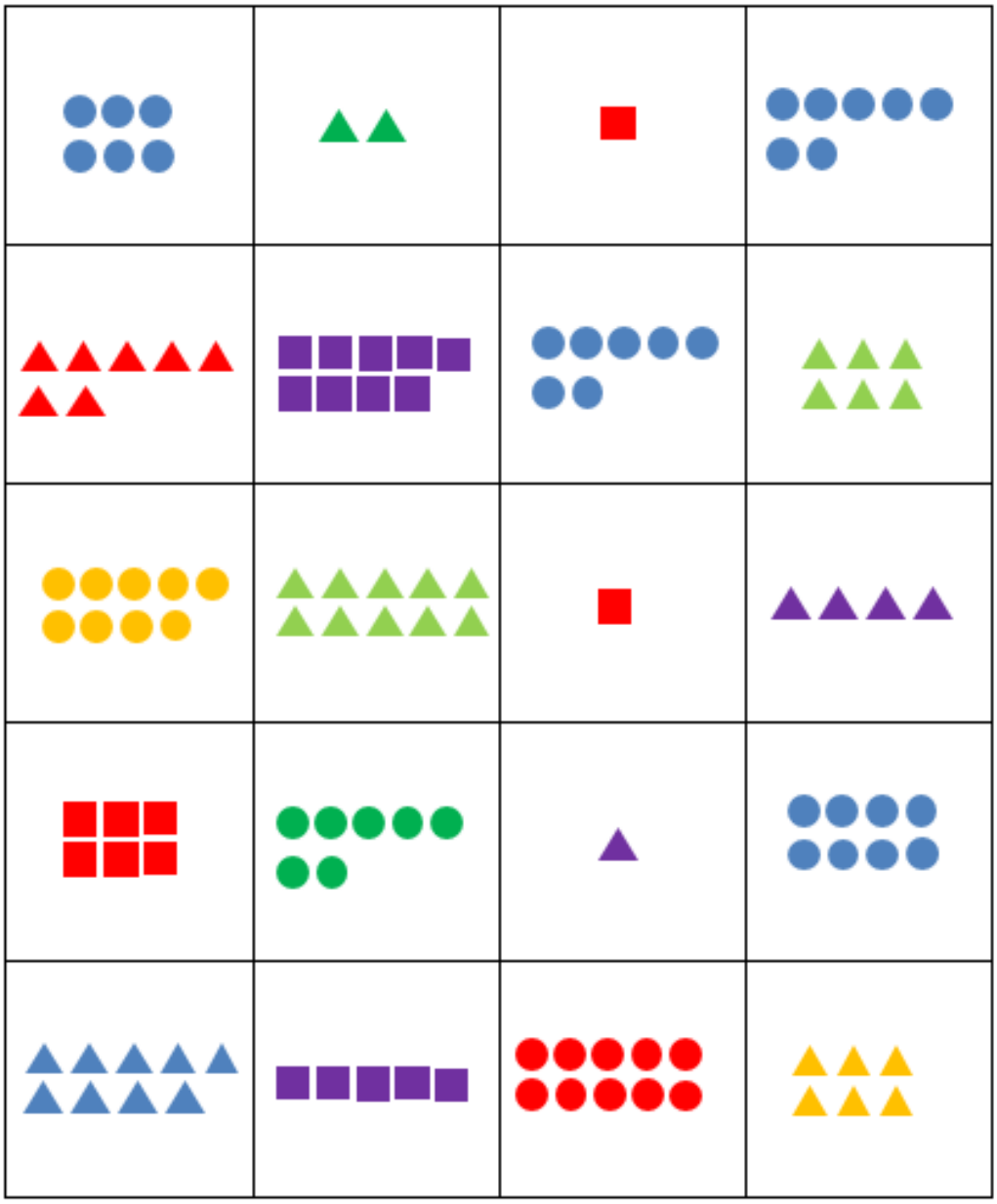
Yours sincerely,

Kate Allison

(Trainee Educational Psychologist)

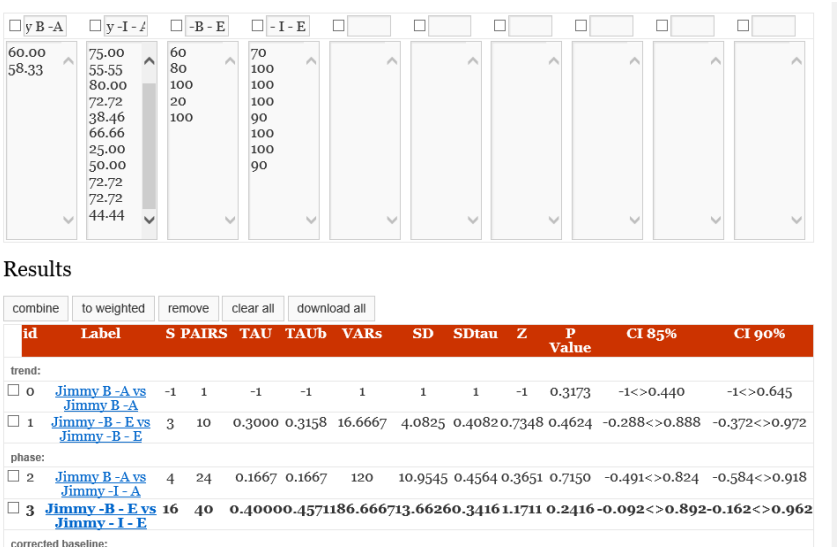
8.20 JIMMY'S MATHS PROBE

Probe – Rational Counting (1-10) (not to size)



8.21 OUTPUT FROM TAU-U ANALYSIS

Jimmy:



y B -A	y -I - A	-B - E	- I - E						
60.00 58.33	75.00 55.55 80.00 72.72 38.46 66.66 25.00 50.00 72.72 72.72 44.44	60 80 100 20 100	70 100 100 100 90 100 100 90						

Results

combine | to weighted | remove | clear all | download all

	id	Label	S	PAIRS	TAU	TAUb	VARs	SD	SDtau	Z	P Value	CI 85%	CI 90%
trend:													
☐	0	Jimmy B -A vs Jimmy B -A	-1	1	-1	-1	1	1	1	-1	0.3173	-1<>0.440	-1<>0.645
☐	1	Jimmy -B - E vs Jimmy -B - E	3	10	0.3000	0.3158	16.6667	4.0825	0.4082	0.7348	0.4624	-0.288<>0.888	-0.372<>0.972
phase:													
☐	2	Jimmy B -A vs Jimmy -I - A	4	24	0.1667	0.1667	120	10.9545	0.4564	0.3651	0.7150	-0.491<>0.824	-0.584<>0.918
☐	**3**	**Jimmy -B - E vs Jimmy - I - E**	**16**	**40**	**0.4000**	**0.4571**	**186.6667**	**13.6626**	**0.3416**	**1.1711**	**0.2416**	**-0.092<>0.892**	**-0.162<>0.962**
corrected baseline:													

Bobbie:



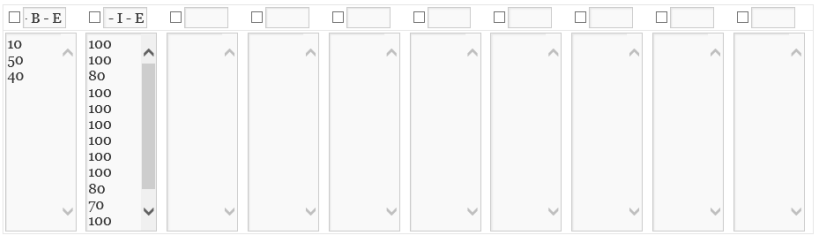
- B - A	- I - A	- B - E	- I - E						
62.50 90.90 73.33 63.63 81.81 70.00	55.55 84.60 72.70 91.66 75.00 81.81 92.85 77.77 90.00 66.66 75.00 80.00	80 60 70 70 100 90	100 90 90 90 60 70 100 60 90 60 80 70						

Results

combine | to weighted | remove | clear all | download all

	id	Label	S	PAIRS	TAU	TAUb	VARs	SD	SDtau	Z	P Value	CI 85%	CI 90%
trend:													
☐	0	Bobbie - B - A vs Bobbie - B - A	1	15	0.0667	0.0667	28.3333	5.3229	0.3549	0.1879	0.8510	-0.444<>0.578	-0.517<>0.650
☐	1	Bobbie - B - E vs Bobbie - B - E	6	15	0.4000	0.4138	28.3333	5.3229	0.3549	1.1272	0.2597	-0.111<>0.911	-0.184<>0.984
phase:													
☐	2	Bobbie - B - A vs Bobbie - I - A	23	72	0.3194	0.3217	456	21.3542	0.2966	1.0771	0.2814	-0.108<>0.747	-0.168<>0.807
☐	**3**	**Bobbie - B - E vs Bobbie - I - E**	**4**	**72**	**0.0556**	**0.0615**	**456**	**21.3542**	**0.2966**	**0.1873**	**0.8514**	**-0.372<>0.483**	**-0.432<>0.543**
corrected baseline:													

Richie:



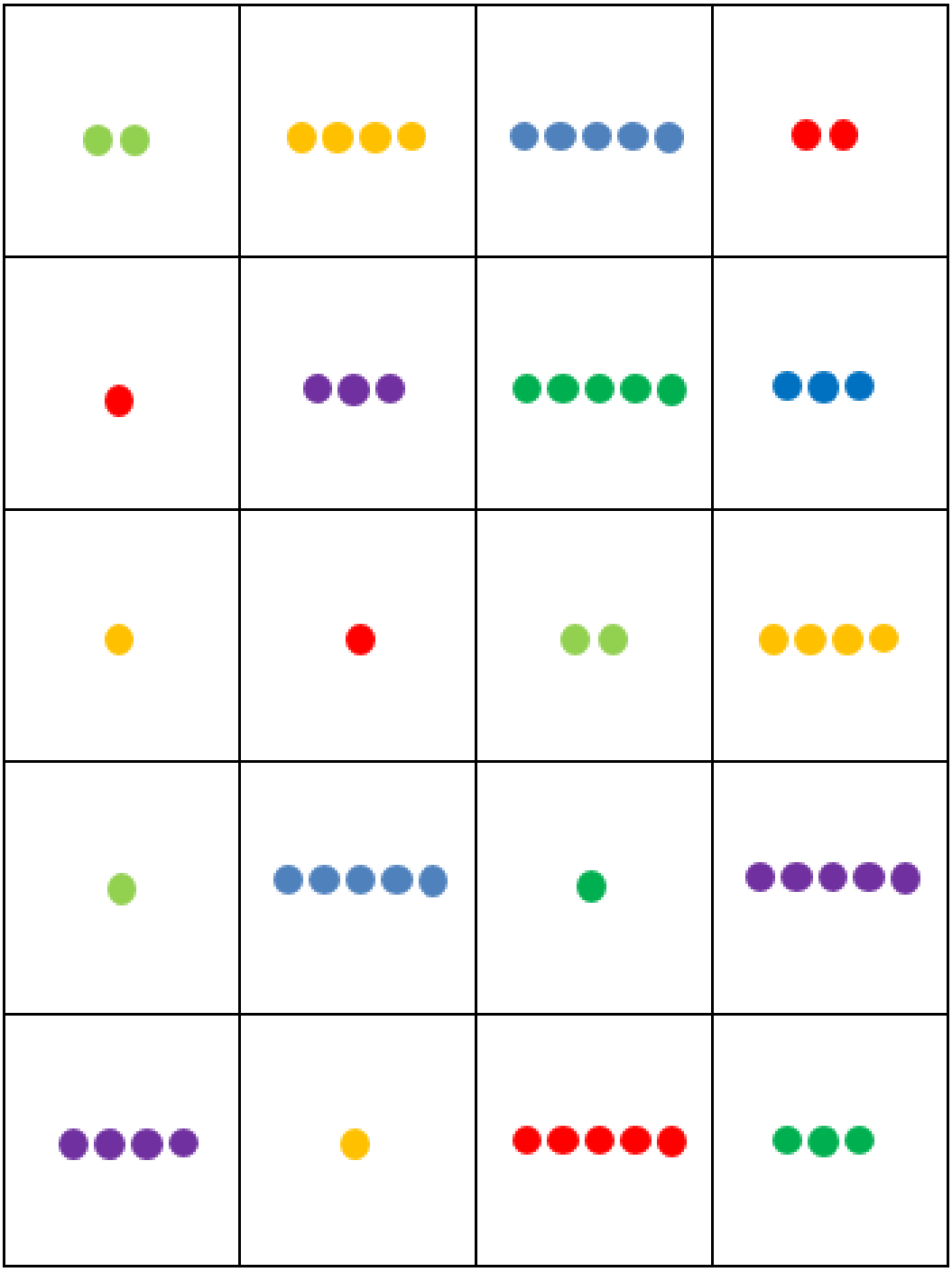
Results

combine | to weighted | remove | clear all | download all

id	Label	S	PAIRS	TAU	TAUb	VARs	SD	SDtau	Z	P Value	CI 85%	CI 90%
trend:												
0	Richie - B - E vs Richie - B - E	1	3	0.3333	0.3333	3.6667	1.9149	0.6383	0.5222	0.6015	-0.586<>1	-0.717<>1
phase:												
1	**Richie - B - E vs Richie - I - E**	**36**	**36**	**1**	**1**	**192**	**13.8564**	**0.3849**	**2.5981**	**0.0094**	**0.446<>1**	**0.367<>1**
corrected baseline:												
-	-	-	-	-	-	-	-	-	-	-	-	-

8.22 Bobbie's Maths Probe

Probe – Rational Counting 1-5 (not to size)



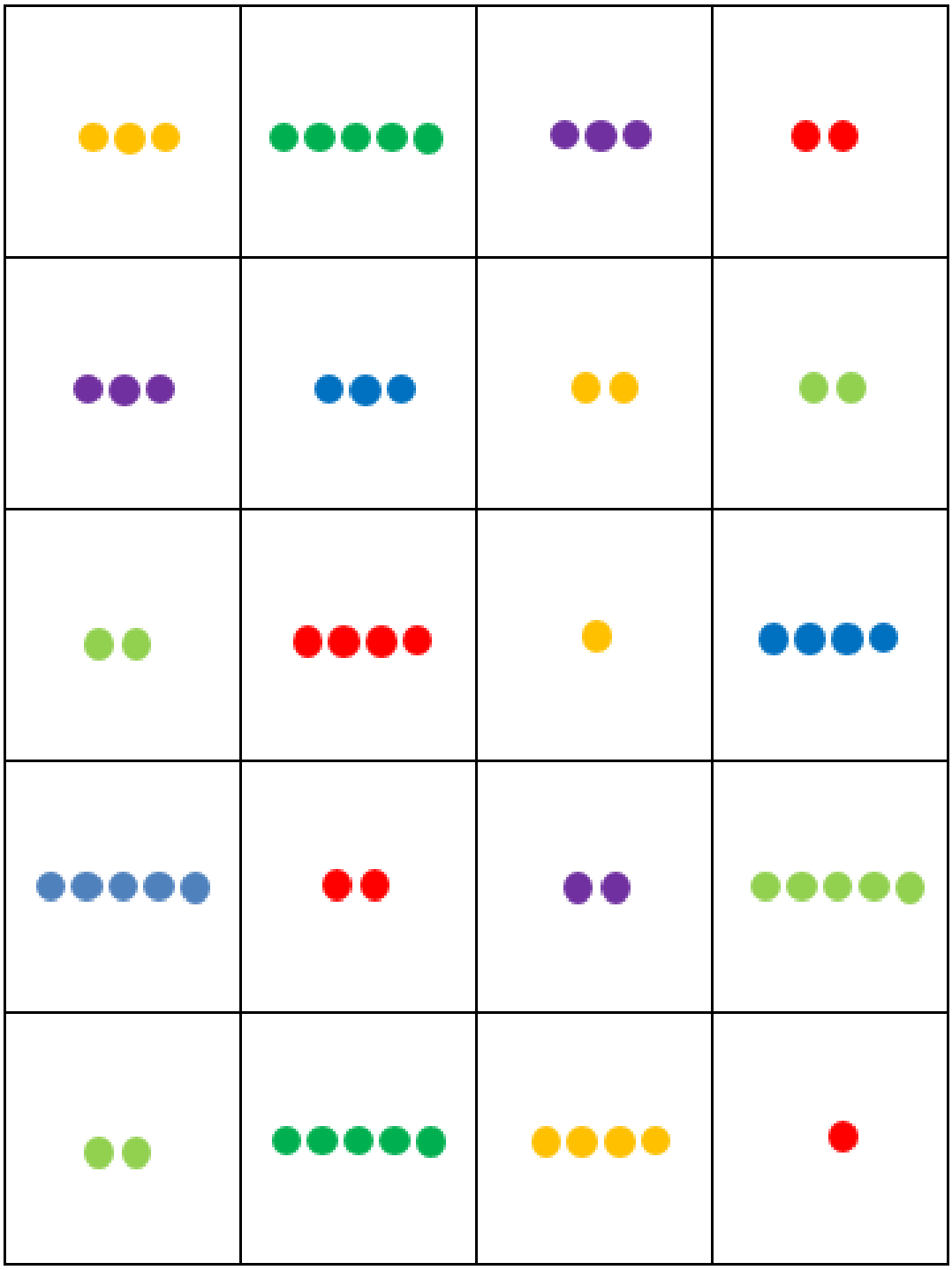
8.23 RICHIE'S MATHS PROBE (PHASE 1)

Probe – Number Recognition 1-6 (not to size)

2	6	1	2
3	3	5	4
5	4	4	1
5	5	5	1
2	1	2	6

8.24 Richie's Maths Probe (Phase 2)

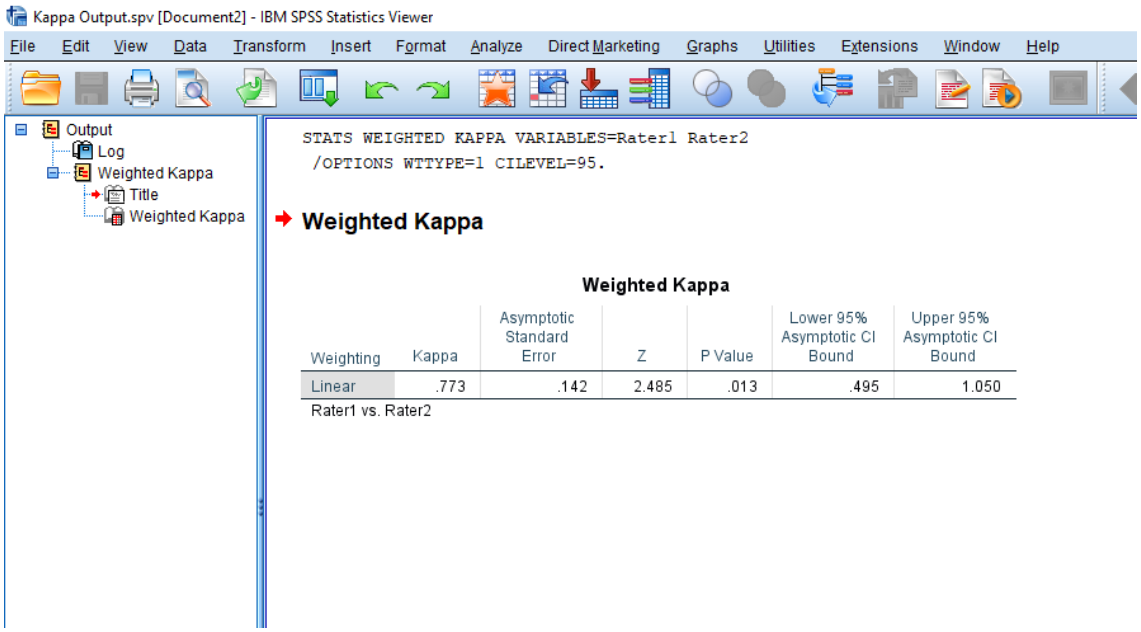
Probe – Rational Counting 1-5 (not to size)



8.25 Intervention Fidelity Checklist

Feature	Evaluation Criteria	Y/N	Additional Comments
Intervention lasts for 15 minutes	Supporting adult allowed the child to interact with the app for 15 mins (15mins +/- 1mins)		
Child accessed their own profile in app and worked through activities	The child was working through the next activities OR activities they had already completed for repetition in their own profile on the app.		
Intervention was accessed in a quiet environment with adult support	Child and supporting adults completed intervention in a quiet, distraction free environment away from class/peers. Either a separate room OR quiet area of a classroom Adult remained with child, supporting when required.		

8.26 KAPPA OUTPUT



8.27 List of Final Codes from Thematic Analysis

Codes across all interviews

Child experienced frustration with the app

Children's previous experience of tablet use effected their interactions with app

Some tasks were too challenging

Facilitator unsure about impact of intervention

Child enjoyed the intervention

Intervention would be improved if it could be aligned with the whole-class teaching

The interventions visuals were appealing

Child did not listen to the instructions

The child was responding through trial and error

Adult was needed to repeat instructions

The adult plans to continue to use the intervention

Adult needed to step in when child not being successful

Adult worked on activities alongside child

Motor skills effected tracing ability

Instructions were too long

The intervention has introduced a tablet as an educational tool

The intervention extended the amount of time the child engaged in maths learning

15 minutes was appropriate amount of time

The intervention is a useful way of repeating the basics

Individual personality effected his engagement

Activities were at an appropriate level for the child

Transferred learning to the classroom

The intervention did not have an impact on the child's learning

Intervention needed to be completed in a quiet environment

Language was suitable for child

App was user friendly

The app was repetitive, reinforcing learning.

Engagement was influenced by child's emotional well-being

Time of the day influenced engagement

The child was motivated by the rewards of stars and certificates

Gestural/Physical support was needed.

Number recognition got better

Patience improved

Guidance on choice of topic was necessary

Child would have played on it for longer

Child listening to instructions

Simple instructions

iPad not previously used education

Made him more confident with maths

Slowed his counting down

Short questions which he could process

Counting has improved

Some of the language was challenging

Linked with his speech and language

Improved his listening and speaking

No change in attitude to learning

8.28 THEMES AND MATCHED EXTRACTS

Themes	**Supporting Codes**	**Contradictions**
The intervention was a positive experience for the pupil and facilitator.	Child enjoyed the intervention "Straight away he was happy. Like I say he loves the iPad anyway so to have a chance on it, with it also being something that is not frequently used in school, it was seen as a treat." (B) "Well if you want to mark it out of 10, 10. He has enjoyed it" (B) "He has absolutely loved the app, we're having to whenever he is on the iPad, we are having to tell him he can't go on the iPad, that app, after he has been on it because he is constantly wanting to press it to play on it." (D1) "He has thoroughly enjoyed it." (D2)	Child experienced frustration with the app "I think he has urm I think he did find it quite frustrating at times, urm some of that is do with that it didn't do the things he wanted it to do rather than you know he wanted to do be able to tap everything" (A)
	The adult plans to continue to use the intervention "Certainly going to try, probably not, we will probably won't fit it in 5 days a week but certainly…" (B) "Do you know what, I will keep having another try because I think it's quite interesting to be able to use it has a little social because it is still learning for her and it will help her." (C)	

	"Yes, definitely. I think it's helped him quite a lot with it, so I think we will carry on using it, to support him with things in the classroom." (D1) **"R: Before we finish, do you think you are going to continue to use the onebillion app?** D2: Yes, I would, I was very sceptical to start with because I just thought this is another thing for us to do, but yes, I will eat my words, it has been really good." (D2)	
The intervention influenced the perception of the use of technology	The intervention has introduced a tablet as an educational tool "It is getting used to the fact that this is more of an educational tool I think is of benefit to him, as I think as he moves on that will possibly be something we have to do more of. So yeh I it is certainly good for that" (A) "Urm like I say I think, I think recognising that we can use the iPad for more than just watching youtube or looking at stories, I think is really good" (A) "I think it's a good thing using the iPad, because I think this is the world that we are living in, technology sort of thing. So, I think it's a good thing because they can do so much and you can do so much can't you on the iPad. There are lots of learning things on the iPad so I wouldn't say no for her because I think it's a good thing as well." (C) "It engages the children. Children nowadays used iPads and things at home, and I think it's the new technology. I think it's the way forward. I think for children with special	"We use the iPad to use literacy apps to help with his words, some numeracy apps to support him in the classroom. To get him recognising numbers 1 to 5, and things like that and little tiny games." (D1)

	educational needs, there is no writing involved. They can easily access it, they can listen and even if I suppose they can't listen there would be some form, they could make it that you just looked at the pictures and you just follow what the pictures do and it was very visual, I think that works really well." (D2)	
	The intervention extended the amount of time the child engaged in maths learning "there is a limit to what I can do in the classroom for 45 minutes to keep him… so it is quite nice that I could say we are going to go outside, we didn't get around to trying it with headphones, and we can carry on doing the number work but it's a bit more (…)" (A) "yes, like I say I think its quite good that this has been brought in as I do thinks its been useful and like I say that keeping him motivated and keeping that maths work going for that little bit longer is really useful so obviously the more he gets used to that the better" (A)	
Improvements in mathematical knowledge and skills	Number recognition got better "I mean he recognises his numbers, he has got better with his numbers, I would say he is recognising up to 20 now." (B)	Facilitator unsure about impact of intervention "So I find that very difficult to …. to judge." (A)

	Counting has improved “the quality of his accurate counting to get those answers was better, rather than finishing the sheets in a minute. Because we started with counting two spots and physically going 1-2 but more often than not we were going 3 by the end of it, so he was visually seeing one two and three, rather than having to count each spot.” (B) “before we did it, when you had objects and you ask him to give you about 5, he wouldn't be able to stop, he would just keep giving them. But now I've noticed that when he does it, he actually counts along with it and he does stop” (D1) “We were working on numbers 1 to 5 but now, we are going up to numbers 1 to 10, because he seems stronger now by using the iPad.” (D1)	
	Transferred learning to the classroom “As I say the patterns I did notice because the teacher wanted, she was doing some assessments and one of them was carrying on a repeated pattern so that one was a nicely linked one.” (A) “It has been nice for us to do, to see the transfer from other things we do. For example, speech and language to turn up on the app and think oh yeah what we have been doing, it has been reinforced and he understands it and that's what you need.” (D2)	

	Slowed his counting down “I think it has made him more confident with his maths… so we've been doing numbers and counting with him and it has really helped him do that because normally he would go really fast counting but this time he has been going quite slowly and pointing to the numbers which he needed to do.” (D1) “Yes, he's going slower now when he's doing it where is he used to go “one two” on one thing and then keep going so you would end up having more” (D1)	
Improvements in other learning skills	Improved his listening and speaking “I think it has helped him with his listening skills and I think it has helped him with his speaking as well” (D2) “I think possibly on the whole listening to the teacher.” (D2) “I just think with him having to listen and he talks away in his own little vocabulary. I just think it's… it helped him with his babbling.” (D2)	No change to attitude to learning “Certainly isn’t any less, possibly … I wouldn’t say it was any more either because urm again because of him and the stage he is at, I do try to make as much of his learning interactive and using resources and things like that because he needs that. So it is not a case of either he is sat with his nose in a book or on a ipad, he hasn’t got that distance between them at the moment” (A) **“What about any changes in his attention and attitude to learning?** B: He has always been good, bless him, he has always been willing, but he has always been willing to have that one to one attention.” (B)
	Made him more confident with maths “I just think it's gone really well. I think he's absolutely loved it, so it's just the trying to keep him off it part that was the hard part. He has absolutely loved it it's just brought his confidence out and that’s really good.” (D1)	

	Patience improved “I think his patience as well. He has always been good at wanting to do his jobs but I think it's slowed him down a little and stopped him from rushing. I think he's starting to realise a purpose behind it. I think he's started to get the concept of quantity a little bit with it.” (B)	

Factors affecting outcomes

Themes	Supporting Codes	Contradictions
Features of the intervention which supported engagement		
Visual Features	The interventions visuals were appealing "mmm yeh so its nice, the graphics are nice and the urm you know the colours and the way it is set out are good." (A) "It's colourful, it's got short bursts, each activity doesn't last long so it holds his interest. It's very colourful and another side for me, is that he has had to listen to it as well." (D2)	
Language and Instructions	Child listening to instructions "The instructor was giving her the instructions so, she was listening. She was listening to her, the woman telling her, so for instance the colour. Because she will listen." (C) "I think the speech with it at first, I thought "uh oh" but we have the volume up and he listens to it and he has been really…really careful." (D2)	Child did not listen to the instructions "he didn't care what the voice was saying" (A)
	Simple instructions "I think the language on some of them, for where his learning is at, was simple enough and it was repeated the same phrases. So even whenever you press that repeat button it was always going to be that same language which a child with his needs, special needs anyway so I think that repetition." (B) "But there's not an awful lot really, it's just saying, it's quite a simple instruction, for instance saying pink cup or blue sock. That sort of thing, it's not a lot of words is it really. So I think it's quite… she could follow it." (C) "I thought it was appropriate for for his needs because they were quite simple instructions so he could follow them straight away" (D1)	Instructions were too long "They seemed a bit wordy for that age group… for someone like Jimmy, he tends to only hear the last word so if it said pick the girl between two boys, he would automatically pick a boy because that's the last thing he heard" (A)
	Short questions with he could process "Because they're so short questions he was able to think oh yeah that's what I need to do and he processed it quite quickly, it was very rarely that you had to ask the question again" (D1)	
	Language was suitable for child "because most of the time he has understood what he needed to do." (D1) "His speech is building up as you can probably realise, but his understanding, when you could hear and there was no background noise, he could understand exactly what was happening on the app. The language was based at children like him." (D2)	Some of the language was challenging "Very rarely it was, just more like when he was doing more or less because we haven't really covered that in the class with him yet so we just had to keep signing "you have, you need to do more" (gesture) and he would do it." (D1)

		"some of the language: short tall; he understands the difference between big and small but the language sometimes he found confusing and when we were doing the positional language he could understand middle, next to, in front of, behind but when it came to left and right he struggled with left and right." (D2)
Pedagogy and instructional level	The intervention is a useful way of repeating the basics "they just need to go back to basics to remember how to count, how to add, how to do the basic things and if they have got something like that just as a reinforcer, in a fun way, then hopefully it might actually give them halve a chance on the rest of the stuff" (A)	Some tasks were too challenging "Some of the apps we started towards the end of it, some of the little sections I would push him away from it because I think it was a bit too confusing." (B)
	Activities were at an appropriate level for the child "that I think it hit topics and subjects, any criteria that we needed." (B) "I think it's been really helpful, because it's been able to support them, and it links in with all the topics that you are doing in the classroom as well. So he has been able to use that to do the work in the classroom" (D1) "I think who ever has in invented this app has known part of the curriculum and I think they have done it very well. There was positional language, we have done about shapes, there was the colours, there was the sequencing, there were lots of things that we have already done." (D2)	Intervention would be improved if it could be aligned with the whole-class teaching "And as I say if I can link it a bit more with the maths they are doing in class so much the better and then hopefully we will… it will be easier to see whether its having much of any effect as well" (A) "I would guided access it now, and I would lock it on something he needs that reinforcement for, that we are doing in class. I would lock it onto that, and we would keep doing it, we would over learn that section, until he has got the 10 questions right. So, I would do the over write for how long it takes, so yeah." (B)
	The app was repetitive, reinforcing learning. "so it was that reinforced, repetitive teaching and I think that was it." (B) "We have pre learnt it, but it reinforced it with the app which was really… there were some things that we haven't done but there was a lot that we had done and it was like yes we have understood this, we have sat in the classroom, and you do understand what we have been doing. That's great." (D2) "It has helped consolidate things you know, do you know what I mean, and that's what you've got to do with these types of children." (D2)	The child was responding through trial and error "again he soon realised that if you tapped on everything eventually, he would get the right one" (A) "Sometimes it was if you keep pressing you would get the right answer so that was a little bit of a negative on the app, because if you pressed it enough eventually he would clicked on the right one on some of the subjects" (B) "sometimes when you have too many goes and they guess… it would be nice if there was something where the computer knows we're not getting that we will go back a level." (B)

	Linked with his speech and language "Some of the things that we have… that are included on the app are similar to what we do in speech and language. Like when you are putting things on the shelf, on the bottom, in the middle, under, behind. We use a lot of that language. That was really good because he transferred his skills from the practical stuff and things that he learnt on the app, which was really good." (D2)	
Facilitators role during the intervention	Adult was needed to repeat instructions "Urm like I say there was a lot of where I was repeating instructions, rewording it, just saying oh look X we didn't hear what the lady said, lets do it again, lets listen to her again" (A) "Early on it was repeating an instruction or using a sign to boost the understanding of the instruction the lady had said. Some of that is down to his hearing and understanding of the language but there was not really much I needed to do." (B) "I just explained to him you just have to listen very carefully to it, and then he seemed to work off after that and he would just keep having a go at it really." (D1)	
	Adult needed to step in when child not being successful "so what I did do once when I thought he was getting a bit frustrated, when he got one wrong, we just went straight back and started the quiz again." (A)	
	Adult worked on activities alongside child "And things like when we had to put things in height order, showing him how to do it, so I modelled it because I knew he wasn't getting it because you had to put four trees in a height order or things like that." (B) "Yeah so we would just go on the programme, and taking turns at first, so we did taking turns, so I would say "Mrs C have a turn" and then "Millie's turn" just to get her engaged so that she could understand it and then she would, she wanted to do it by herself at the beginning." (C)	
	Gestural/Physical support was needed. "I think having some sort of sign in the corner of the screen would be a good option, if it's going to be aimed at helping special needs as well. A little bit of a help and a visual clue especially with things like in on and under, the prepositions, and the colours." (B) "I would guide his hand by the wrist and help him over write. But he was doing the number!" (B) "I have a couple of times told him to press the… to say the instructions again, or if he didn't get it, I would press it again and I would sign with it." (D1)	

	Guidance on choice of topic was necessary "I would go back and change the section because I didn't think it was appropriate, or if he went a bit flighty and it was like 'no it's asked you to do the flashing icon', because I let him just go get used to the app, we would go back and try and finish and get all the stars on this or go back and go 'flashing' but in the end he started looking for it himself" (B) "Just to make sure he didn't flick too quickly between… between the different activities. That he concentrated on one at a time rather than thinking "I'm three questions in now I'm going to go back and do something else" trying to make him "you've got to wait an answer the ten questions once you've got your tick you can go on to the next thing". Just making him be patient" (D2) "It's no good putting them on it and not sitting with them, if you know what I mean, I think they still need someone there to make sure, especially with Richie, that they aren't just clicking on twenty, thirty, forty different things and not getting the benefit from it." (D2)	
Environmental Factors affecting engagement		
Length of Intervention	15 minutes was appropriate amount of time "Yeh, I would say especially when he was getting to only play on 1 or 2 games, not particularly that he was getting bored, sometimes he was, but again its that if he is settled and wants a couple more minutes that's fine, we can extend it a little bit more, but if he is not then it is not too longer that we are fighting to keep him doing something or risking him doing a runner or something like that." (A) "I will probably do 10 minutes, just because of getting everything else in in the school day. But I certainly wouldn't do any less than 10 minutes. I wouldn't do anything less than 10 or 15 minutes, but just because of what we need to get in in the school day, I think it's long enough. I think it's just long enough actually." (B) "I think it's quite a reasonable time because more or less after 15 minutes then he would start getting distracted, so it's a good time slot for him, so yeah" (D1) "Yes I do, I think when he was engrossed in something we could have probably gone on for longer but then I think if you go on for too long it's too, I think 15 minutes is a good marker because sometimes if you go over that I think it can be too long and you're not using it for the right reasons." (D2)	Child would have played on it for longer "He would continue longer but I think for the purpose behind it, what we need him to get out of it." (B)

Place	Intervention needed to be completed in a quiet environment "Quiet environment. I found that at the time about, that a quiet environment where lots of routines hadn't happened before" (B) "we have done it in quiet areas so he could listen and focus on it." (D1) "He just loves playing on it, there is not very many times when he has been distracted as long as it is in a quiet area, he has been absolutely fine with it." (D1) "In a quiet room. I would recommend, because with children, especially ones with educational needs they need time to process the information that the app is saying to them, but if there are other things going on around them, they might not be good at filtering that out." (D2)	"I think probably shorter than 15 minutes. I think 15 minutes for her is probably too long. I think probably 5-10 minutes at most, I think maybe the 15 minutes is too long." (C)
Time of day	Time of the day influenced engagement "There was one time I had to do it after last play, and he was tired, he didn't want to do it. That's the only time he didn't want to do it, he just got distracted" (D1) "I think probably if he has used it in the morning, he is probably been more accepting of it because towards the end of the day he does get tired." (D2)	"He was quite happy no matter what the time was really" (B)
Characteristics of the Individual		
Motor Skills	Motor skills effected tracing ability "Well definitely that tracing one, getting a bit more consistency on that one, because for someone like X, his motor skills aren't, we are doing a lot of work on letter formation and number formation but it is just so frustrating, you know I'm sat there thinking that's really mean and because it didn't, it just kept going 'durrr', back to the beginning 'durr', try again 'durr' and there was no let me show you again or nothing like that, it would just have kept doing that forever and a day" (A) "I think it was the overwrite one, if I remember correctly it was a bit pernickety about how accurate it needed to be… it was a bit too pernickety for a child with coordination issues." (B)	
Emotional Well-being	Individual personality effected his engagement "No, I think it was just, it's just her, her giving the call, that sort of thing." (C)	
	Engagement was influenced by child's emotional well-being "Like, if he was really tired, so some days we could do it in the afternoon, like the hour after lunch, within that criteria, and he will be fine. But the next day because he was tired, so it was more that, it was more to do with something that had gone on or he's	

	been told off because he goes in a right mood. Sit there and sulk. So, it was more that than anything, there wasn't much" (B) "But then I think it depends on the mood of her, sometimes she would get a bit agitated" (C) **"R: So, you mentioned that's to do with mood?** C: Definitely, on the day, how she is, and I think it depends on maybe how she has come in. Because that would speak volumes about how much work we would get out of her in the day as well." (C)	
The child's previous use of technology	Children's previous experience of tablet use effected their interactions with app "he didn't actually want to listen to instructions and do what it was telling you to do. Again that's the iPad though isn't it, they are so used to them and just being able to do what they want on them" (A) **"R: But he did that all independently…**B: Oh yeah, I mean at home he can put things on Apple drop, and you know, his sister's been watching something and the next minute it's changed because he's flicked it onto something else via a phone" (B) "I don't really know why, he's very when it comes to iPads and computers, he is very much aware how to use them. He doesn't need much support using things like that but he's a very intelligent little boy, it's just getting his words out of him." (D1)	
	iPad not previously used education "So, she would always work that way and we wouldn't work on the iPad to work. So, unless she does anything like that at home, we haven't really used the iPad for to do as in school work. We've always done it in our books." (C)	